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The determinants and consequences of women’s fertility preferences and fertility in a rapidly acculturating Amerindian population

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The determinants and consequences of women's fertility preferences and fertility in a rapidly acculturating Amerindian population

A dissertation submitted in partial satisfaction of the

requirements for the degree Doctor of Philosophy

in Anthropology

by

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The determinants and consequences of women's fertility preferences and fertility in a rapidly acculturating Amerindian population

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Lisa Sheina McAllister

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Thank you also to the Tsimane Health and Life History Project directors, postdoctoral scholars, graduate students and staff. Without your logistical support, training, friendship and the access to the Tsimane you enabled, I would have been very lost. I am forever in your debt. Thank you to Dr. Michael Gurven and Dr. Hillard Kaplan for the opportunities the Tsimane Health and Life History Project has provided me, and for your advice and support as its directors. Special thanks to Dr. Jonathan Stieglitz and Dr. Helen Davis, for that initial field training and ongoing advice throughout the years.

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Thank you to my colleagues in the Anthropology Department at UCSB, and especially in Integrative Anthropological Sciences and Evolutionary Psychology, and my colleagues in the Broom Center for Demography. Interacting with these wonderful people, and being able to explore my research ideas with their support and input, has been stimulating, inspirational and nurturing. Special thanks to Dr. Melanie Martin, Dr. Christopher von Rueden, Dr. Katherine Hanson Sobraske, Dr. Carolyn Hodges-Simeon, Angela Garcia and Sarah Alami for always believing in me. Thank you too to Dr. David Lawson and Dr. Michellle Brown for their encouragement and advice.

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CURRICULUM VITAE

RESEARCH INTERESTS

The influence of biocultural factors on human production, reproduction and health from a life history perspective.

- The effects of market integration, and socioeconomic and ecological changes, on women's and men's reproductive preferences and fertility; and, consequently women's reproductive health and autonomy.
- Allocation of resources to the competing demands of growth, reproduction, and somatic maintenance, and how disruption of this affects women's and their children's long-term health and well-being.
- Developing cross-culturally applicable experimental methods to determine the casual pathways and specific environmental cues that influence human reproductive decision making and fertility.
- Local causes of international migration in Nicaragua, Belize and Honduras, and how migration affects: (1) household security, vulnerability and resilience; (2) household dynamics, including the division of labor and power; (3) family planning and health; and (4) childhood development and growth.

EDUCATION

University of California, Santa Barbara

2017 Ph.D. in Anthropology, Department of Anthropology
Advisor: Dr. Michael Gurven
Emphases in: Quantitative Methods for the Social Sciences; and Demography

2009 M.A. in Anthropology, Department of Anthropology
Thesis Advisor: Dr. Michael Gurven

University of Liverpool, Liverpool UK

2003 M.Sc. in Evolutionary Psychology, Department of Biology
Thesis Advisors: Prof. Robert Dunbar, Dr. Louise Barrett and Dr. John Lycett

Imperial College London, London UK

2002 B.Sc. in Zoology, Department of Biology.
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External

2015 Human Behavior and Evolution Society Student Travel Grant ($175)

2014 NESCent Working Group Research Grant, Duke University ($10,000)
Student Travel Grant, University of California Global Health Day ($345)

2012 Student Travel Grant, University of California Global Health Day ($350)

2010 NSF Doctoral Dissertation Research Improvement Grant #1060319 ($18,467)

2005 Travel and living expenses funding, UNM-UCSB Tsimane Health and Life History Project

Internal

2012 Department of Anthropology Summer Research Grant ($500)

2011 Spalding Fellowship, UCSB ($2500)
Department of Anthropology Summer Research Grant ($1500)

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2006-2007	Funding for Undergraduate Research Assistants, UCSB
2004-2012	Non-resident and Resident Fees Fellowships, UCSB

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2012	Fiona Goodchild Award for Excellence as a Graduate Mentor of Undergraduate Research

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<u>*Peer-Reviewed*</u>

2016	**McAllister, L.**, Pepper, G., Hackman, J., Virgo, S., Sobraske, K., Coall, D., The evolved psychological mechanisms of fertility motivation: Hunting for causation in a sea of correlation. *Philosophical Transactions B.*
2016	Coall, D., Tickner, M., **McAllister, L.**, Sheppard, P. (2016) Developmental influences on human fertility decisions: An evolutionary perspective. *Philosophical Transactions B.*
2014	Veile, A., Martin, M., **McAllister, L.**, Gurven, G. (2014) Modernization is Associated with Intensive Breastfeeding Patterns in the Bolivian Amazon. *Social Science & Medicine.* 100: 148-158
2012	**McAllister, L.**, Gurven, M., Kaplan, H., Steiglitz, J. Why do women have more children than they want? Understanding differences in women's ideal and actual family size in a natural fertility population. *American Journal of Human Biology.* 24(6):786-799
2009	Gurven, M., Winking, J., Kaplan, H., von Rueden, C., **McAllister, L.** A bioeconomic approach to marriage and the sexual division of labor. *Human Nature.* 20(2):151-183

<u>*Other Publications*</u>

2016	Sears, R., Pepper, G., **McAllister, L.** Demography needs you! Why demography needs psychologists. *The Psychologist.*

FIRST-AUTHORED PRESENTATIONS

2016	**McAllister, L.**, Gurven, M. Too sick to have another baby: Effects of perceived health on family planning in the Bolivian Amazon. *American Association of Physical Anthropology; Atlanta, GA.*
	McAllister, L., Blackwell A., Garcia, G., Gurven, M. Teenage pregnancy compromises maternal growth but not reproductive success among the Tsimane, Bolivian forager-famers. *Human Biology Association; Atlanta, GA.*
2015	**McAllister, L.**, Shenk, M., Tweed, D., Jaeggi, A. Mortality and Family Planning: using experimental methods to find a causative link between mortality and reproductive preferences. *Human Behavior and Evolution Society, Columbia, MO.*
	McAllister, L., Blackwell A., Garcia, G., Gurven, M. Who Reaps the Rewards and Who Pays the Costs of Precocious Investment in Reproduction? Adolescent Reproduction in the Bolivian Amazon. *Population Association of America; San Diego, CA.*
2012	**McAllister, L.**, Blackwell A., Garcia, G., Gurven, M. Human Growth and Development, Motherhood and Reproduction. *American Anthropological Association; San Francisco, CA.*

McAllister, L., Blackwell A., Garcia, G., Gurven, M. Does Teenage Reproduction Compromise Growth. *Human Behavior and Evolution Society; Albuquerque, NM.*

McAllister, L., Gurven, M., Kaplan, H. Why Do Women Have More Children Than They Want: Understanding Excess Fertility in Bolivian Amerindians. *Population Association of America; San Francisco, CA.*

McAllister, L., Gurven, M., Kaplan, H. Why Do Women Have More Children Than They Want: Understanding Excess Fertility in Bolivian Amerindians. *American Association of Physical Anthropologists; Portland, OR.*

McAllister, L., Gurven, M., Kaplan, H. Reproductive Decision Making in the Bolivian Amazon. *UC Global Health Day; Berkley, CA.*

2010 **McAllister, L.**, Gurven, M., Kaplan, H. The determinants and consequences of women's fertility preferences and fertility outcomes in a rapidly acculturating Amerindian population. *Vienna Institute of Demography; Vienna, Austria.*

McAllister, L., Gurven, M., Kaplan, H. Market Integration and Fertility in an Amerindian Population**.** *Human Behavior and Evolution Society; Eugene, OR.*

McAllister, L., Gurven, M., Kaplan, H. Market Integration and Fertility in an Amerindian Population**.** *Annual 3UCs Conference; San Luis Obispo, CA.*

2008 **McAllister, L.**, Stonich, S. Tourism and Fertility: The effects of tourism development on Belizean women's fertility**.** *VI Taller Internacionalde Turismoen el Caribe; Cozumel, Mexico.*

2007 **McAllister, L.**, Gurven, M., Kaplan, H. Acculturation and Reproductive Decision Making In The Tsimane Of Bolivia. *Human Behavior and Evolution Society; Williamsburg, VA.*

FIELD RESEARCH

Current

2015 - **Research with Nicaraguans on Big Corn Island, Nicaragua**

- Developing fertility and reproductive decision making components for a project on health and adolescent development with Carolyn Hodges-Simeon, Ph.D., Boston University, MA.

2014 - **Research with students across eleven universities and the U.S. general public**

- Project manager and co-PI, under Mary Shenk, Ph.D., University of Missouri, for the project *Psychological Mechanisms of Fertility Motivation*. This research aims to take relationships among environmental cues and fertility preferences, theorized from demographic and anthropological research, and elucidate causal pathways using experimental methods adapted from experimental psychology. In 2017, this work will be adapted to be applicable in field settings for a cross-cultural study with people at different levels of subsistence across South America, Africa, Europe and Australia.

2010 - **Research with the Tsimane, Bolivian forager farmers (Ph.D. Dissertation)**

- Topics of research include the determinants and consequences of women's fertility preferences and fertility in a rapidly acculturating Amerindian population, and the health and developmental consequences of adolescent reproduction.

Past

2008 **Research with residents of three coastal towns in Belize**

- Site manager in Punto Gorda, Belize for the project *From Vulnerability to Resilience: Helping People and Communities Cope with Crisis,* under PIs Susan Stonich, Ph.D., University of California Santa Barbara, CA, and Sara Alexander, Ph.D., Baylor University, TX. Explored the effects of tourism and environmental crisis on family planning.

2005 **Research with the Tsimane, Bolivian forager farmers (M.A. Thesis)**

- Topics of research included the effects of acculturation on Tsimane women's views on success, and parental investment decisions.

UNM-UCSB Tsimane Health and Life History Project

- Supervised by Michael Gurven, Ph.D., University of California Santa Barbara, CA, and Hillard Kaplan, Ph.D., University of New Mexico Albuquerque, NM. Explored subsistence patterns, resource accrual and sharing networks, and division of labor.

2002 **Research with post-menopausal women in the U.K. (M.Sc. Thesis)**

- Topics of research included exploring parental investment decisions across three generations and their long-term reproductive consequences, and the feasibility of applying evolutionary and life history theories to modern societies.

ACADEMIC POSITIONS

Instructor of Record at University of California, Santa Barbara, CA

Human Variation, ANTH 105 (Summer 2016, 2013 & 2012)
Primate Behavior, ANTH 153T (Winter 2013, Fall 2010, Winter 2010 & 2007, Spring 2006)
Primate and Human Sexual Behavior, ANTH 153 (Spring 2010, Fall 2008 & 2007)

Teaching Assistant at University of California, Santa Barbara, CA

Introduction to Physical Anthropology (Summer 2015, Fall 2012 & 2011, Spring 2007 & 2005, Fall 2004); Introduction to Chicano History (Fall 2009); Third World Environments (Spring 2009); Hunters and Gatherers (Winter 2009); Human Variation (Winter 2006); Introduction to Cultural Anthropology (Winter 2005)

Guest Lectures

California State University, Channel Islands, CA

Adolescent Reproduction and Health, Course: Medical Anthropology, Instructor: William Adams, Ph.D.
Demographic Transition and Fertility, Course: Medical Anthropology, Instructor: William Adams, Ph.D.

Santa Barbara City College, Santa Barbara, CA

Gender and Sexuality, Course: Introduction to Cultural Anthropology, Instructor: Rani Mclean, Ph.D.

University of California, Santa Barbara, CA

Adolescent Reproduction, Course: Human Growth & Development, Instructor: Aaron Blackwell, Ph.D.
Understanding Genetics, Course: Human Variation, Instructor: Sabrina Curran, Ph.D.
Evolution and Natural Selection, Course: Human Variation, Instructor: Sabrina Curran, Ph.D.
Demographic Transition and Fertility, Course: Human Variation, Instructor: Sabrina Curran, Ph.D.
Variation in Human Skin Color, Course: Human Variation, Instructor: Phillip Walker, Ph.D.
Reproductive Decisions in Hunter-gatherer Societies, Course: Anthropological Demography and Life History, Instructor: Michael Gurven, Ph.D.

PROFESSIONAL EXPERIENCE

2014 - **Project Manager: Psychological Mechanisms of Fertility Motivation (University of Missouri, MO)**

- Site recruitment; managing 35 affiliated professors and graduate students across eleven universities; Human Subjects Committee liaison; method and survey design; utilization of Qualtrics, SONA systems and Amazon Mechanical Turk.

2012 **Certificate recipient, Summer Teaching Institute for Associates (UCSB, CA)**

- Short course for teaching associates focused on interactive learning, and course planning, conduct and evaluation

2008 **Site Manager in Punta Gorda, Belize: From Vulnerability to Resilience: Helping People and Communities Cope with Crisis (Baylor University, TX)**

- Site setup; local government liaison; recruitment and training of five local research assistants; survey design and implementation; community mapping.

2005 **Site Manager in Tacuaral del Mato, Bolivia: UNM-UCSB Tsimane Health and Life History Project (University of New Mexico, Albuquerque, NM and UCSB, CA)**

- Training and management of 4 local research assistants; local community liaison for the project; training in various field methods; medical support.

STUDENT MENTORING

2012 **Supervised Geni Garcia's undergraduate honors thesis (UCSB, CA)**

- Provided training in project development and the scientific method, data base building and management, statistical analysis and the use of statistical software (SPSS), project write up, and presentation at conferences. Received the *Fiona Goodchild Award for Excellence as a Graduate Mentor of Undergraduate Research*. Ms. Garcia graduated with Honors in 2012 and presented her research at the 2014 UC Global Health Day at UC Davis, CA.

Supervisor for UCSB Summer Research Program for Gifted High School Students

- Recruited, trained and managed three gifted High School students for 6 weeks. Provided training in project development and the scientific method, data base building and management, statistical analysis and the use of statistical software (SPSS), project write up, and public presentation skills.

2006 - **Supervised undergraduate independent research (UCSB, CA)**

- Recruited, trained and managed nine undergraduate research assistants for various projects related to the UNM-UCSB Tsimane Health and Life History Project.

ACADEMIC AND COMMUNITY SERVICE

Organizations Chaired

2011-2012 Organizer, Anthropology Graduate and Undergraduate Annual Research Symposium

2008-2009 Co-president, Anthropology Graduate Student Association

2004-2011 Co-organizer, Anthropology Fundraising

Symposia Organized

2016 Biocultural perspectives on family health within and across generations. *American Association of Physical Anthropology; Atlanta, GA.*

2015 When to start, when to stop? Insights from life history theory on fertility decisions. *Human Behavior and Evolution Society; Columbia, MO.*

Invited Reviewer

Evolution and Human Behavior
International Journal of Fertility and Sterility
Psychoneuroendocrinology
American Public Health Association Student Presentations
University of California Global Health Day Presentations

Other Service

2014 - Creator and Manager of the Tsimane Flood Relief Fund, https://sites.google.com/site/tsimanefloodrelief

2011-2013 Grant Writer, Community Outreach Center for the Santa Barbara Birthing Center

2011-2013 Campus Economic Projects Representative, University of California Haiti Initiative

2011-2013 Graduate Student Representative, Student Initiated Outreach Programs

2004-2011 Co-organizer, Anthropology Fundraising

2004-2007 Organizer, Anthropology Graduate Student Association Events

PROFESSIONAL AFFILIATIONS

Member, National Evolutionary Synthesis Center Working Group: Integrating Evolutionary Models of Human Fertility Change

Graduate Associate, UCSB Broom Center for Demography

Member, American Anthropological Association

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Indigenous Demography; Human Behavioral Ecology; Family Planning and Dynamics; International Migration; Nutritional and Economic Security; Health/Development Vulnerability; Applied Anthropology

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ABSTRACT

The determinants and consequences of women's fertility preferences and fertility in a rapidly acculturating Amerindian population

by

Lisa Sheina McAllister

Teenage pregnancy, short interbirth intervals and high fertility are associated with a host of poor health and socioeconomic outcomes for mothers and their children. International population policies espouse that reducing mortality risk and increasing women's educational attainment encourages delayed reproduction, prolongs interbirth intervals and lowers fertility. This is consistent with evolutionary theorizing. Life history theory suggests that reproductive timing and effort is influenced by mortality risk and resource access. When mortality risk declines, returns to investments in own and children's embodied capital increase. As individuals move from a subsistence to a market based economy prolonged investment in embodied capital, specifically education, increasingly predicts adult resource accruement.

However, health and education initiatives in developing countries have inconsistent results. Examining the proximate mechanisms by which cues of mortality and education attainment influence reproductive timing may elucidate why failures occurred, and advance theory. This dissertation examines, within an Amerindian forager-farmer population: (1) how individual differences in mortality experiences and perceptions influence reproductive timing and effort; (2) whether education can effectively encourage delayed reproduction without

returns to investments in educational capital; and (3) if precocious reproduction is a rational choice.

This research presents data from interviews conducted with 177 Tsimane women from 2010-2011, supplemented with reproductive history and anthropometric data from the Tsimane Health and Life History Project. Mortality risk whether perceived or experienced influences women's reproductive preferences and behaviors, but not as theory predicts. For example, perceived mortality risk predicted later, not earlier, preferred age of first birth; and exposure to older sibling deaths delayed first births, while exposure to younger sibling deaths prompted first births. Greater educational attainment did not predict preferences for delayed reproduction; however, women who perceived higher returns to investments in educational capital preferred older ages of first birth. In summary, perceptions of mortality risk and returns to investment in educational capital influence reproductive timing, but complicate simplistic predictions from life history and embodied capital theories.

Despite equivocal relationships between mortality risk, educational attainment, and age of first birth, precocious reproduction may benefit Tsimane maternal reproductive fitness. In a population where kinship size affects resource access and socio-political power, and children provide labor and care in old age, high fertility women are the most successful. Until returns to investments in embodied capital are realized women may be unmotivated to delay reproduction, and may utilize improvements in health or resource access to reproduce earlier and increase their fertility.

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I. Introduction

Adolescent reproduction and high fertility are associated with a host of poor health and socioeconomic outcomes for mothers and their children (Agustin Conde-Agudelo, Belizán, & Lammers, 2005; Gibbs, Wendt, Peters, & Hogue, 2012; Gunderson et al., 2012; Schnall, Scholl, & Hediger, 1994; World Health Organization, 2012; Zabin & Kiragu, 1998). For example, adolescent mothers face higher risks of maternal death, violence, disability, and violations of rights to education, employment and reproductive health than women who delay their first birth until age ≥20 (Chandra-Mouli, Camacho, & Michaud, 2013; Loaiza & Liang, 2013). International population policies espouse that increasing women's educational attainment encourages delayed reproduction and reduces fertility. While life-history theory and evolutionary demography suggest that reducing mortality risk, thus enabling greater investment in self and in child quality, is also pivotal to increasing age at first birth and reducing fertility (K. Hill & Kaplan, 1999; Low, Parker, Hazel, & Welch, 2013; Migliano, Vinicius, & Lahr, 2007; Rebecca Sear, Lawson, Kaplan, & Shenk, 2016). Millions are spent annually on programs to educate and protect at-risk-girls from adolescent reproduction, and to encourage contraceptive use and smaller family sizes (Chandra-Mouli et al., 2013; UNFPA, 2013). However, health and education initiatives in developing countries have inconsistent effects on fertility (John Bongaarts, 2006, 2008; Howse, 2015; Shapiro & Gebreselassie, 2009).

Women are unique among female mammals in that they compete in cultural systems where success is measured in both biological (e.g. health and parity) and economic terms (e.g. accrued wealth and material possessions) (Borgerhoff Mulder, 2000; Leonetti et al., 2007), and experience increased reproductive rates and longer periods of pre-adulthood, with extended childhood, juvenility and adolescence (Gurven & Walker, 2006). Women, in addition, make conscious reproductive decisions, often based on internalized reproductive preferences. These reproductive preferences in turn reflect desired fertility outcomes of preferred age at first and last birth, inter-birth intervals, offspring sex ratio and family size (Bushan & Hill, 1995), and can directly impact reproductive success, socioeconomic success and health (John Bongaarts, 2001; Nettle, Coall, & Dickins, 2011). Evolutionary theory suggests that, ultimately, women's reproductive preferences should prioritize reproductive scheduling that maximizes their reproductive success given their mortality risk, and finite resources, which must be divided between their own biological and socioeconomic needs, and those of their children (Jasienska, 2009). In traditional societies, reproductive success correlates strongly with resource access, but, this is not true in socioeconomically developed societies where both preferred family size and actual fertility are low, despite women's increased access to economic resources (Kaplan, 1996; Vining, 1986). The question thus emerges: **what are the sources and consequences of individual differences in reproductive preferences and behaviors? And, how are these affected by the changes in mortality risk and resource access associated with socioeconomic development?**

These questions are especially relevant considering the recent population growth rates of many Amerindian populations, which suggest that their "demographic transition" may be different from that of urban and historic populations where socioeconomic development (changes in how resources are gathered, ability to accrue resources and what resources are valued) reduced mortality rates and led to delayed reproduction and later declines in fertility rates (Hern, 1994; Jackson, 1975). Instead many Amerindian groups' birth rates are increasing, despite some declines in mortality risk, improved education, and women's preferences for smaller family sizes (Hern, 1994; Lu, 2007; Terborgh et al., 1995). The growing discrepancies between women's reproductive preferences and actualized fertility can negatively affect their and their children's health, survival, socioeconomic status and reproductive autonomy (McSweeney & Arps, 2005).

Moreover, most Amerindian groups have limited land rights or upward socioeconomic mobility; they are often confined to their homelands and, due to the land and associated ecology being their primary source of food, they cannot afford the environmental degradation associated with overpopulation (Speidel et al., 2007). Theories explaining why women exceed their preferred family sizes predominantly hinge on women's lack of reproductive autonomy coupled with husband's higher preferred family sizes (Cleland & Van Ginneken, 1988; Jejeebhoy, 1995; Scrimshaw, 1978) or a limited ability to control fertility (Bryant, 2007). These theories do not fully explain the fertility of many acculturating Amerindian women, women that have increased reproductive autonomy, declining discrepancies between their and their husbands' preferred family sizes and access to modern contraceptives (Bledsoe et al., 1998; Bull, 1998; Terborgh et al., 1995), nor do they explain the accelerating population growth of many Amerindian groups (McSweeney & Arps, 2005). A second question thus emerges: **why, for many Amerindian women is there a growing contradiction between their preferred family sizes and fertility, despite socioeconomic development?**

A. Theory

Expecting reduced mortality risk and increased educational attainment to delay reproduction and lower fertility is consistent with evolutionary theories — such as life history theory, and related embodied capital theory — applied to fertility reduction. Individuals have finite time and energy, which can be invested in accrual of resources for reproduction or survival. The demographic transitions during recent human history to older ages of first birth and smaller family sizes may be due to changing payoffs to resource investment in oneself and one's offspring (i.e. investments in embodied capital).

When extrinsic mortality is high, earlier reproduction increases fertility and reproductive success by compensating for shorter adult lifespans and higher rates of offspring mortality (Caudell & Quinlan, 2012; Hill & Kaplan, 1999; McAllister et al., 2016; Stearns, 1989; Stearns, 1992). A major cost of earlier reproduction is lower somatic (e.g. growth) and extra-somatic (e.g. education) investment in self. However, when the returns to these investments in self are only realized in the future, they should be discounted under high mortality risk conditions as that future is unlikely to happen.

When extrinsic mortality is low, differential reproductive success is contingent on resources invested in growth, reproduction and parenting effort: In low extrinsic mortality environments, individual fitness is enhanced by delayed reproduction, allowing for greater investment in self and resource accrual, and lower fertility combined with greater investment per offspring.

Moves away from the general mammalian pattern of extrinsic mortality risk being negatively associated with age of first birth and positively associated with fertility may be explained by evoking human culture and considering the ecological niche humans fill. For many millennia, humans have filled a skill-intensive method of resource accrual niche within hunter-gatherer economies (Kaplan, Lancaster, Tucker, & Anderson, 2002a). Only relatively recently have humans developed market-labor economies. Consequently, the evolutionary pressures of market economies, including a need for extra-somatic wealth to accrue resources, which is better obtained through greater investment in own and children's embodied capital (e.g. education) are novel. As individuals shift from a subsistence to a market-based economy, and access to resources is increasingly monetized, prolonged investment in embodied capital, specifically education, becomes increasingly useful to compete successfully in the labor market, i.e. to accrue resources for reproduction (Hill & Kaplan, 1999; Kaplan et al., 2002a). Investments in educational capital increase an individual's knowledge and skill set, which theoretically increases their access to and monetary value within the labor market (Becker, 1965, 2009; Willis, 1973). For women, significantly more so than men, time spent investing in education and joining the labor market directly conflicts with investing in reproduction, and there is a higher opportunity costs of bearing children in terms of potential lost income (Becker, 1965). Consequently, women are older at first birth, reducing their reproductive lifespan and lowering fertility.

Education may also increase women's economic independence and bargaining power within the household, including their ability to achieve their reproductive preferences (Abadian, 1996; Jejeebhoy, 1995). Also, assuming education allows women to earn money in "honorable" occupations, women's prestige within the family may become decoupled from their reproductive achievements, and shift to being accrued through education, knowledge and economic contribution (Akman, 2002; Jejeebhoy, 1995).

Given differences in ecologies and individual abilities (e.g. variations in mortality risk, ability to influence mortality risk, access to education, and payoffs to education) variation within and between populations in the effects of health and education initiatives on fertility should be expected. Examining the proximate mechanisms by which cues of mortality, and costs and benefits of schooling influence reproductive timing may elucidate why some initiatives fail to encourage delayed reproduction or lower fertility, and help advance theory.

It is also important to consider that variation in reproductive timing and effort may reflect alternate life history strategies, in which individuals optimize reproductive effort considering their own ecologies and abilities. Given the diversity of environments and cultures humans inhabit, and the complex physiological and psychological mechanisms influencing human reproduction, it is not surprising that there is wide variation in reproductive timing and effort, and in the responsiveness of these reproductive parameters to health and education initiatives. For example, a growing body of literature suggests that adolescent reproduction is a viable and evolutionary normative strategy under conditions of resource stress, psychological stress, paternal absence, and/or high extrinsic mortality (Chisholm et al., 1993; Ellis, 2004; Geronimus, 1996; Kramer & Lancaster, 2010; Migliano, Vinicius, & Lahr, 2007; Walker et al., 2006; Wilson & Daly, 1997). It is thus important with any population or individual to consider local ecology, culture and individual abilities, and whether adolescent reproduction or high fertility is an optimal choice for increasing reproductive success, or possibly status, access to alloparents, mate quality, or income.

For example, when individuals have low socioeconomic mobility, status remains tied to reproductive achievements, and children provide labor and care in old age; in such contexts, why should education encourage delayed reproduction or lower fertility? A better understanding of the costs and benefits of precocious reproduction in marginalized populations, may help clarify why improved health and access to education are not always sufficient incentives to delay reproduction. Is teenage pregnancy an irrational choice or an optimal strategy when women have low socioeconomic mobility and their status remains tied to their reproduction?

B. Research Objectives

This dissertation examines the causes and consequences of individual differences in reproductive preferences and behaviors, and how these are affected by different aspects of socioeconomic development, among women of the Tsimane, Amerindian forager-horticulturists of central Bolivia. Specifically, I ask: (1) how do individual differences in mortality experiences and perceptions influence reproductive preferences and behaviors; (2) can education effectively encourage delayed reproduction without actual or perceived returns to investments in educational capital; and (3) given the ecological and cultural constraints faced by the Tsimane, what are the costs and benefits of adolescent reproduction and high fertility?

The Tsimane constitute an especially important research population as they have been experiencing increasing access to the local market economy since the 1970s, though such access has been variable across the Tsimane territory, resulting in intra- and inter-village heterogeneity in access to healthcare, education and economic resources, despite retaining cultural homogeneity. Other relevant demographic features also vary among villages. For example, infant mortality rates vary from 8% in villages near town (i.e. where health care is reliably accessible) to 26% in more remote villages (Gurven, 2012a).

C. Organization of dissertation

This dissertation is organized into five chapters that examine Tsimane women's reproductive preferences and behaviors given their experienced and perceived mortality risks, and their educational attainment and perceived returns to investments in educational capital. Whether precocious reproduction is a viable and successful strategy given the ecological and socioeconomic constraints faced by Tsimane women is also explored.

Chapter II details two studies. The first investigates how perceptions of mortality risk may influence women's reproductive preferences for themselves and their children. Perceived mortality risk was associated with later, not earlier, preferred age of first birth for both sons and daughters. This may suggest that traditional life history theory assumptions that extrinsic mortality risk in unaffected by behavior or investment decisions may not apply to humans. Preferences for delayed reproduction in children, despite perceiving high mortality risk, may track a desire to (indirectly) encourage improved grandchild survivorship. Perceived mortality risk was associated with smaller preferred family size for daughters and larger preferred family size for sons. This may suggest that the differential reproductive potential of sons versus daughters is an important component of mothers' reproductive preferences for their children.

The second study in Chapter II investigates how childhood exposure to mortality risk, proxied as number of siblings who died in infancy, affects reproductive timing and effort. In my data, exposure to older sibling deaths was associated with delayed first births and lower parity-for-age; while, exposure to younger sibling deaths associated with earlier first births. These findings suggest that older sibling deaths, deaths a woman did not directly experience, may change the parenting environment in ways that encourage greater investment in self and a few children. While younger sibling deaths may be considered a direct indication of local mortality risk to which women respond as expected with earlier and greater reproductive effort.

Chapter III explores the effects of women's educational attainment on their preferred age of first birth for their children. Greater educational attainment did not predict preferences for delayed children's reproduction. Women's own education was not associated with preferred age of first birth for daughters and trended towards a negative association with preferred age of first birth for sons. This may suggest, assuming that educational attainment indicates "quality" (sensu Becker 1960; Lack 1947, 1954), and high quality women have high quality sons, that more educated women prefer their higher quality sons to invest heavily in reproduction, including starting reproduction early, to make best use of their greater reproductive potential. However, women who perceived higher returns to investments in educational capital preferred older ages of first birth for both sons and daughters. This suggests that until greater returns to investments in embodied capital are realized, women may be unmotivated to encourage their children to delay their reproduction.

Chapter IV examines whether precocious reproduction is a rational choice when women have low socioeconomic mobility and when their status remains tied to reproductive (as opposed to social or economic) achievements. My findings suggest that better childhood condition (larger BMI and height-for-age) enables earlier age of first birth. However, reproduction before age 16 constrains maternal growth (though it does not lead to cessation of maternal growth), and is associated with lower infant and child survival rates. Still, precocious reproducers had more surviving children, suggesting that among the Tsimane early ages of first birth may be beneficial. In a context where larger families and extensive kin networks affect resource access and socio-political power, and where children continue to provide labor and care in old age, high fertility women are often viewed as the most successful. Until greater returns to investments in embodied capital are realized, women may be unmotivated to delay reproduction, and may instead channel improvements in health or resource access to earlier and more frequent reproduction.

Finally, Chapter V synthesizes the results of this dissertation, presents general conclusions and suggests future research directions. How the findings here may help adjust current demographic transition and life history theory to help explain reproductive behaviors in marginalized non-Western populations is also discussed.

II: The effects of experienced and perceived mortality on women's reproductive preferences and outcomes

This chapter is co-authored with Aaron Blackwell, Hillard Kaplan and Michael Gurven. Kaplan and Gurven as directors of the Tsimane Health and Life History Project provided some of the Tsimane data used herein and logistical support in the field. Blackwell provided invaluable statistical advice and training. The author of this dissertation proposed all hypotheses tested herein and collected in Bolivia all data discussed in Study I. The analyses, writing, and figures contained in this chapter are the work of the author of this dissertation.

A. Introduction

Life history theory suggests that reproductive timing and investments are influenced by three environmental factors: (1) harshness (e.g. proxied by age-specific mortality and morbidity rates); (2) unpredictability (e.g. consistency of harshness over time); and (3) resource scarcity (e.g. access to energetic resources, including level of competition for them) (Betzig, 1996; Chisholm et al., 1993; Hill & Hurtado, 1996; Promislow & Harvey, 1990; Stearns, 1992). Life history strategies reflect the energetic and temporal trade-offs among investment in growth and maintenance, current reproduction, and future reproduction in ways that are believed to have historically maximize biological fitness (Stearns, 1992).

Across species, including humans, the influence of harshness, unpredictability and resource scarcity on the underlying physiological mechanisms that regulate life history strategies are relatively well understood (Ellison, 2001). For example, women with greater access to resources are better able to meet the energetic requirements of reproduction: They are fecund at younger ages and have quicker resumption of post-partum fecundity, and consequently may have longer reproductive lifespans and a faster pace of childbearing (Valeggia & Ellison, 2009).

Across small-scale societies practicing natural fertility, mean age at first birth varies from 16.2 among the Wichi of Argentina to 25.7 among the Gainj of Papua New Guinea (R.

Walker et al., 2006); and within the United States of America mean age at first birth varied in 2006 from 22.6 in Mississippi to 27.7 in Massachusetts (Mathews & Hamilton, 2009). Physiological differences do not fully account for this wide variation in life history strategies (Chisholm et al., 1993; Hill & Kaplan, 1999; World Health Organization, 2006.). For example, within the United States , a national survey found that among married women, aged 15 to 44, 12% had impaired fecundity; however, despite correlations with socioeconomic status, education and ethnicity, no variation by state has been noted (Chandra, Copen, & Hervey Stephen, 2013). Additionally, fertility in all human populations is well below the theoretical maximum given local environmental conditions and individual physiology (Harpending, 1994; Hill & Hurtado, 1996; Kaplan, 1996; Lawson, Alvergne, & Gibson, 2012; Pennington & Harpending, 1988; Worthman, 2003). This suggests that in humans the regulation of reproduction is more than just a physiological process.

In fact, humans have an unprecedented degree of control over their reproduction with preferences for age at first birth, length of inter-birth intervals, offspring sex ratio, and completed fertility (John Bongaarts, 2001; Bushan & Hill, 1995; Voas, 2003). Crucially, reproductive preferences associate strongly with reproductive decisions (Bushan & Hill, 1995; Hagewen & Morgan, 2005; McAllister, Gurven, Kaplan, & Stieglitz, 2012; Rindfuss, Morgan, & Swicegood, 1988; Schoen, Astone, Kim, Nathanson, & Fields, 1999; Thomson, 1997; Westoff & Moreno, 1996). Reproductive decisions, in tandem with physiology and opportunity, govern human fertility.

The areas in which reproductive preferences are exerted at the individual and population level – proximate determinants of fertility -- are relatively well known (John Bongaarts & Potter, 1983). However, despite almost a century of research (Caldwell, 1982; K O Mason, 1997; Thompson, 1929; Wood, 1994), the formation of human reproductive preferences and subsequent reproductive behavior remains poorly understood. Most research on the relationship between reproductive preferences and fertility has focused on the influence of conditions that are evolutionarily novel (e.g. formal schooling); or characteristics of social groups (e.g. comparing nations by gross domestic product) and average reproductive behavior of those groups. These approaches can only account for preferences of people facing novel environments, and the focus on group averages is unlikely to explain variation in individual life history strategies. No current research fully accounts for the formation of reproductive preferences or their functional relationship to fertility considering (1) conditions present in deep evolutionary time, and (2) the strategies of individuals, not groups.

It has long been postulated that humans have psychological mechanisms that monitor environmental conditions and mediate reproductive preferences and subsequent behavior alongside physiological mechanisms (David, 1981; Kaplan, 1994; Miller, 1986, 1995; Philipov, 2011). However, the underlying mechanisms of human reproductive decision making and behavior are rarely studied directly, and, thus, are poorly understood. Consequently, the specific cues of harshness, unpredictability and resource scarcity that humans are attuned to, and that influence our reproductive preferences and behavior, are unknown.

Here we utilize longitudinal data gathered by the Tsimane Health and Life History Project, and data gathered by LSM in 2010 and 2011 to test associations among: (1) women's experiences (sibling and own child deaths in infancy) and perceptions (perceived infant, child and adult mortality and morbidity) of environmental harshness and their reproductive preferences for their children and themselves; and (2) women's experiences of environmental harshness and their age at first birth, rate of progression to second birth, and fertility-for-age.

1. The association between harshness and reproduction

Within and among species, extrinsic mortality rates are positively associated with indicators of faster life history strategies (Angeles, 2009; Low, Hazel, Parker, & Welch, 2008; Low et al., 2013; McAllister, Pepper, Virgo, & Coall, 2016; Placek & Quinlan, 2012). When extrinsic mortality is high, earlier reproduction extends the reproductive lifespan (Caudell & Quinlan, 2012; Hill & Kaplan, 1999; McAllister et al., 2016; Stearns, 1989; Stearns, 1992). This increases fertility and reproductive success by compensating for the high rate of offspring mortality. When extrinsic mortality is low, differential reproductive success is contingent on resources invested in growth, reproduction and parenting effort: In low extrinsic mortality environments, individual fitness is enhanced by delayed reproduction, allowing for greater investment in self and resource accruement, and lower fertility combined with greater investment per offspring.

In humans, those with shorter life expectancies on average are younger at reproductive maturity, younger at first birth (Figure 1) (Angeles, 2009; Low et al., 2008; Placek & Quinlan, 2012; R. Walker et al., 2006; Wilson & Daly, 1997), and have larger family sizes than those with longer life expectancies (Figure 2) (Low et al., 2013; Nettle, 2010; Quinlan, 2010). High infant mortality has been associated with earlier ages at first birth , shorter inter-birth intervals (especially following an infant death), reduced parental investment, and higher fertility (Palloni & Rafalimanana, 1999; Quinlan, 2007, 2010).

However, the relationship between infant mortality and human reproduction is complex. For example, across Latin America declines in infant mortality rates were only weakly associated with the process of fertility decline after ~1910 (Palloni & Rafalimanana, 1999). Also, at very high rates of infant mortality delayed age at first birth has been observed (Quinlan, 2010). This may be due to the conditions that encourage high infant mortality rates also encouraging somatic depletion and energetic stress in women, and consequently impaired fecundity. Additionally, high infant mortality risk may indicate an environment is too harsh for any reproductive effort to be successful, so investment in reproduction is delayed in hopes that the environment will improve in time (Ellis, 2004). It is also known that earlier ages at first birth and shorter inter-birth intervals are risk factors for infant mortality (Hobcraft, McDonald, & Rutstein, 1983; Kaplan, Hooper, Stieglitz, & Gurven, 2015; LeGrand & Phillips, 1996; Palloni & Rafalimanana, 1999). This generalization of mortality risk and observable bi-directionality, coupled with the strong correlation between resource scarcity and mortality risk, make it a challenge to unravel the specific elements of the environment humans monitor when developing their life history strategies.

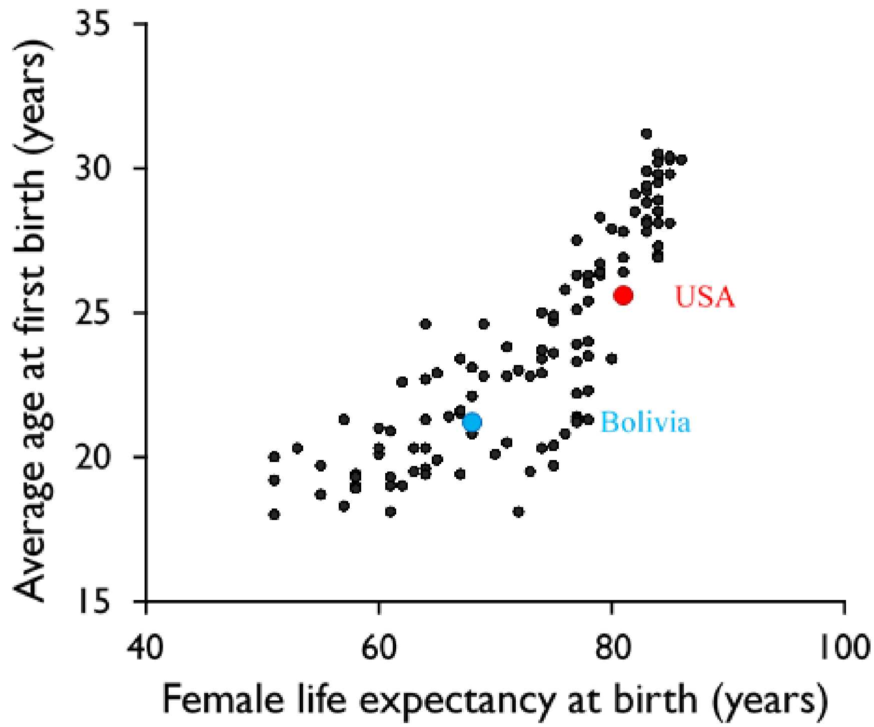


Figure 1. Women's mean and median (taken for women aged 20-24 or 25-29 depending on the population) ages at first birth by female life expectancy at birth for 115 countries. Average age at first birth is taken from the CIA World Factbook. Life expectancy is for the year the average age at first birth was recorded

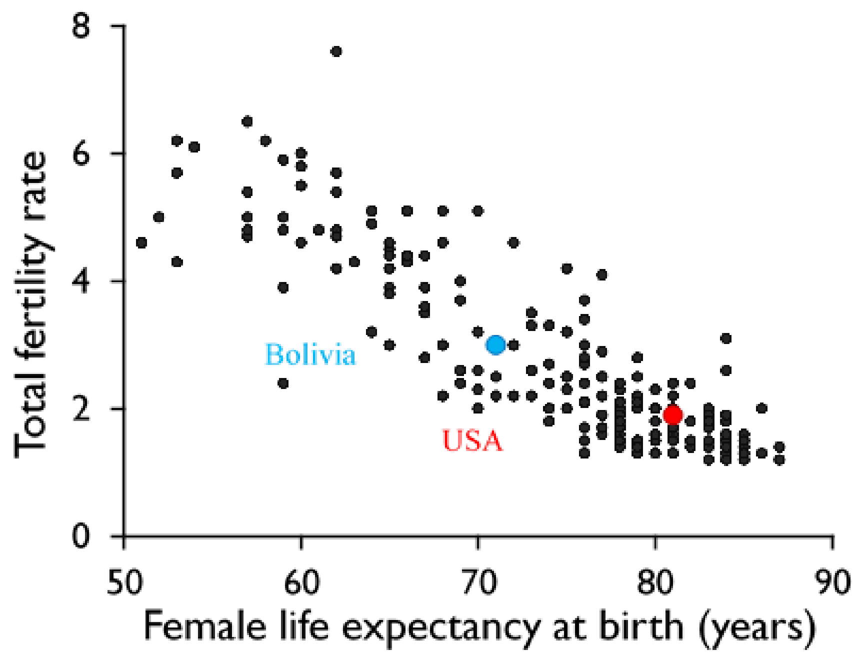


Figure 2. Total fertility rate by female life expectancy at birth in 2014 for 195 countries. Data taken from The World Bank. The red dot is the USA (2014, female life expectancy at birth = 81, total fertility rate = 1.9). The blue dot is Bolivia (2014, female life expectancy at birth = 71, total fertility rate = 3).

Furthermore, research on the relationship between mortality and reproduction is confounded by difficulties differentiating between intrinsic and extrinsic mortality components, which can have profound and diverging influences on adaptive behavior (Caudell & Quinlan, 2012). Extrinsic mortality is the age specific mortality risk shared equally by all members of the population independent of individual trade-offs in investment in self versus reproduction (Stearns, 1992). Intrinsic mortality is the risk of dying contingent on an individual's condition – a product of individual resource access and allocation of resources to somatic investment.

2. Cues of Mortality Risk

Childhood exposure to high extrinsic mortality has been associated with faster life history strategies: younger age at first birth, intensified reproductive scheduling, and lower parental investment (Burton, 1990; Chisholm, Quinlivan, Petersen, & Coall, 2005; D. Coall, Dickins, & Nettle, 2012; Low et al., 2008; Nettle et al., 2011; Placek & Quinlan, 2012; Quinlan, 2010). Conversely, childhood exposure to low extrinsic mortality -- commonly associated with higher costs and future payoffs to investing in children -- is associated with delayed and reduced reproduction (Low et al., 2008). However, research on the effects of childhood exposure to differing extrinsic mortality risks is confounded by correlation between mortality and resource scarcity. As such, it sheds little light on the specific mortality cues we are attuned to, or the underlying mechanisms of response that encourage faster or slower life history strategies and corresponding reproductive behavior.

One possible mortality cue is childhood exposure to sibling deaths (Störmer & Lummaa, 2014): High sibling mortality has been linked to earlier marriage and first birth among historic populations in Germany, Finland, and Canada. More generally, the infant mortality rate in women's communities during their childhoods and their year of first birth have been shown to have a quadratic relationship with age at first birth and the pace of reproduction in a Caribbean community (Quinlan, 2010). Infant mortality rate in childhood and during the year of first birth were inversely related to age at first birth, and positively associated with parity-for-age, except under conditions of extremely high infant mortality (>40 infant deaths per 1000 live births) where the relationships reversed. However, the environmental conditions that encourage high infant mortality rates also encourage somatic depletion and energetic stress reducing women's fecundity.

The mechanisms by which mortality experiences influence reproduction remain poorly understood (McAllister et al., 2016; Quinlan, 2010). How do individuals' experiences and perceptions of mortality influence their reproductive decisions? A possible pathway may be that experiences and perceptions of mortality and possibly morbidity risk influence reproductive preferences. These reproductive preferences in turn influence men's and women's mate seeking, sexual receptivity, and parental investment behaviors, amongst others.

Here we present two studies designed to elucidate the relationship between childhood and adult experiences of environmental harshness and women's life history strategies, and whether reproductive preferences are an important component of how experiences of environmental harshness influence life history pace.

Our first study addresses whether women's life history strategies are also related to experiences of morbidity and mortality in adulthood. Theoretically, women's life history strategies should be adaptable to local conditions allowing women to accelerate or slow their rate of reproduction to better fit current, and predicted future, conditions. Here, we explore how women's own number of children that died in infancy (controlling for parity) influences their future reproduction. We also explore a possible pathway by which experiences of morbidity and mortality may be assessed and influence women's life history strategies: Women's perceptions of their local morbidity and mortality rates. Perceived morbidity risk is taken as women's perceived morbidity risk for local children and themselves, and perceived mortality risk as perceived mortality rates of local infants and young children (1 to 5 years old). We expect, among a population with a high pathogen load and where most infant deaths are associated with infectious diseases, that perceptions of morbidity risk and mortality risk will be correlated.

In this first study, we assess women's life history strategies through several proxies – specifically their reproductive preferences for themselves and their children. The assumption being that women on faster life history trajectories will have preferences for their children and themselves associated with faster life history strategies (e.g. younger ages at first birth, shorter interbirth intervals and larger completed family sizes) compared to women on slower life history strategies. Given that a woman's ability to "follow" her dispositional life history strategy is affected by myriad factors, including opportunity (e.g. access to mates), which she may have limited control over, we use reproductive preferences as proxies for women's "ideal" reproductive strategies. However, these preferences may be highly influenced by cultural norms. By working among the Tsimane, a culturally homogenous society of Bolivian forager-farmers, we hope to reduce this concern and assume that variation in reproductive preferences are a result of different life history strategies. We expect to observe different life history strategies among the Tsimane, as morbidity, mortality and fertility vary among and within villages.

Our second study addresses whether early exposure to high infant mortality rates encourages faster life history strategies, as supported by the work of Störmer & Lummaa

(2014), and Quinlan (2010). We investigate how number of siblings that died in infancy (controlling for sibship size), and whether these siblings died before or after a woman was born, associates with women's progression to first and second birth, and her parity-for-age (a suggestion of faster or slower than average rate of reproduction).

B. Study Population

1. Fertility

The Tsimane are forager-farmers residing in the Beni Department of Bolivia. The Tsimane marry and begin their reproductive lives at relatively young ages, even compared to Bolivia as a whole, where ages of first birth are comparatively young (Table 1). In 2008, median age at first birth among Tsimane women aged 25-29 was 17.9 compared to 19.0 among non-Tsimane in Beni and 21.2 across Bolivia (Coa & Ochoa, 2008). 67.1% of Tsimane women aged 20-24 in 2008 gave birth before age 20, compared to 55.9% in rural Beni, and 39.6% for Bolivia as a whole. The adolescent fertility rate (ages 15-19) for the Tsimane is 237 per 1000, compared to 139 per 1000 in the Beni, and 88 per 1000 for Bolivia.

Table 1. Reproductive averages and mortality rates for Tsimane women born 1952 to 1992 (N = 1335).

Trait	
Reproduction (mean ±SD)	
Age at menarche	12.95 ±0.96
Age at marriage	16.00 ±1.97
Age at first birth	18.25 ±2.60
Interbirth interval after miscarriage (months)	23.02 ±12.03
Interbirth interval after live birth (months)	29.64 ±9.99
Total fertility rate	9.1
Mortality	
Fetal mortality rate[a]	5.5%
Infant mortality rate[b]	12.6%
Child mortality rate 1-5 years[b]	1.2%
Child mortality rate 6-15 years[b]	0.4%
Maternal mortality rate[c]	0.7%

a. Fetal mortality rate is from retrospective reproductive histories of 363 Tsimane women who had 121 miscarriages and 2195 pregnancies known to the mother. Taken from Gurven (2012).
b. Mortality rates are for 1990-2002 and are taken from Gurven et al (2007)
c. Maternal mortality among the Tsimane is estimated at 702 deaths per 100,000 live births (from 1972 to 2012 30 deaths due to complications of pregnancy or child birth out of 4275 live births).

However, non-Tsimane residents of Beni, although starting their reproductive lives only slightly later than the Tsimane, stop having children much earlier: Among non-Tsimane women, fertility rates are 134 per 1000 women aged 35-39 in rural areas and 95 per 1000 in Bolivia as a whole, compared to 315 per 1000 among the Tsimane. Total fertility rate among the Tsimane is 9.1 compared to 3.9 among non-Tsimane in Beni, and 3.1 for Bolivia. Tsimane fertility has also not declined as the national fertility rate has over the past decades (from 6.8 in the 1970s (Reed, 1998)). Instead, given Tsimane women's lack of deliberate cessation of reproduction before menopause, fertility may be increasing among the Tsimane. In 2013, the proportion of Tsimane women aged 20-24 who had a first birth before their 20th birthday was 74.2%, 7.1% higher than in 2008; and the median age at first birth for women aged 25-29 had dropped from 17.9 in 2008 to 17.2. Higher rates of adolescent fertility have been noted by the Tsimane. Among a subsample of Tsimane women (N=49), 53.1% said that women have their first births at younger ages now than they did 10 to 20 years ago, while 18.4% said age at first birth was unchanged and 28.6% that women have their first birth at older ages now than in the past. To quote a 31-year-old woman with seven children, from a riverine community: *"[In the past] women married later and [thus] had their first child later. Now jovencitas (teenage girls) have babies. Before jovencitas did not want to look for husbands, now they look for husbands.*"

2. Contraceptive Use

The lower fertility of non-Tsimane Beni women is largely achieved through contraceptive use, with 60.3% of married Beni women using some form of contraception (44.1% using a modern method of contraception) (Coa & Ochoa, 2008). Contraceptive use is comparatively low among the Tsimane: Among a subsample of 165 Tsimane women from seven communities ranging in level of market integration, and access to education and healthcare, only 29.1% had ever used a contraceptive, and those that had did so sporadically and often incorrectly, limiting their effectiveness. This is despite contraceptives being free for the Tsimane, 70.3% of Tsimane women knowing what contraceptives are (subsample of 165 women in which those that knew of contraceptives knew of an average of 2.81 types of contraceptives), and the use of contraceptives among older parous Tsimane women to stop reproducing being culturally condoned.

However, this is not to say the Tsimane make no effort to control their fertility. Tsimane women use several plants grown in their own house gardens or harvested from the forest to "control" their fertility. Use of these plants is believed to delay age at first birth, prolong interbirth intervals, ensure smaller family sizes and induce miscarriages. Among a subsample of Tsimane women asked about herbal contraceptives (N = 145) and abortives (N=150), 78.6% knew of herbal contraceptives and 58.7% of herbal abortives; although, ever use of herbal contraceptives was only 44.1% and herbal abortives 10.7%.

The efficacy, potency and actual effects of these plants remain untested. Furthermore, although increasingly considered taboo, inducing miscarriages through consumption of alcohol or shock injuries to the abdomen (e.g. purposefully falling on a log), and infanticide are practiced. However, despite available methods of fertility control, Tsimane women, unlike Bolivian nationals, continue to reproduce into their early 40s being either pregnant or lactating from ~18 to 45 years old.

3. Mortality and Morbidity

The Tsimane have a high infant mortality rate (Table 1) that is inversely correlated with distance to town (i.e. distance to healthcare) (Gurven 2012). For example, infant mortality ranges from 8% in villages near the urban center, San Borja, to 26% in more remote villages (Gurven, Kaplan, & Supa, 2007). Compare this to non-Tsimane in Beni where the infant mortality rate was 3.9% (Coa & Ochoa, 2008), and the national level which was 5.0%, having declined from 17.3% in the 1960s (The World Bank, 2015). The life expectancy of Tsimane men and women is relatively low: Between 1990-2002 the life expectancy for women was 54.0 and for men 54.3 (Gurven et al., 2007). Life expectancy from birth in Bolivia was 68 for women and 64 for men in 2010 (Haub, 2010). The Tsimane also have high parasite and infectious disease loads, though these also inversely vary with distance to town (Blackwell et al., 2015; Gurven, 2012a; Gurven et al., 2007; Stieglitz et al., 2012).

Additionally, access to health care varies widely for the Tsimane. For most Tsimane visits with healthcare professionals and associated treatments must be paid for. However, in San Borja the hospital provides free healthcare for infants and pregnant women through funding provided by the Universal Mother and Child Insurance Scheme, and numerous pharmacies provide antibiotics and other medicines without prescription for a small cost. Near San Borja there is Horeb, a Tsimane medical outpost that provides more affordable healthcare and family planning to the Tsimane.

However, access to these healthcare providers depends on ability to travel and stay away from home for an extended period of time. Cost and difficulty of traveling to town increase with distance to town, and are dependent on the season. Some Tsimane villages are within 30km, as the crow flies, from town, and residents have year-round ready access to town services; however, most Tsimane villages are situated far from town along logging roads or larger tributaries of the Maniqui River (see Figure 3). During the dryer months (May-August) the riverine communities find town increasing difficult to access as the tributaries dry up limiting travel by boat or canoe, and dramatically increasing travel times. During the wetter months (December-March), villages along logging roads become inaccessible to vehicles: The logging roads are not maintained and bridges over tributaries are often destroyed. In addition, walking through mud for several days, sleeping outside in the rain, and the high risk of flooding make travel to town inhospitable for these villagers. For all Tsimane there is also concern over where to stay in town and what to eat, who will watch over children left behind in the village, and who will protect agricultural fields and the home from theft.

There is also a medical outpost and Catholic Mission in Fatima -- a large, remote, Tsimane village situated on the Maniqui River -- that provides medical care in exchange for produce, meat, handmade goods (e.g. woven roofing panels), or minor manual labor to Tsimane within 1-2 days walking distance (Figure 3). Doctors, nuns and Tsimane health promoters from this village sporadically visit nearby villages to give lectures about hygiene, and provide medical care and consultations. There is also a free and widespread vaccination program for children. Health professionals visit to vaccinate all children under 5 years of age several times per year. However, these vaccine programs are: (1) not always well understood by Tsimane parents and are often mis-associated with causing illness; (2) voluntary and dependent on being in the right village at the right time; and (3) rarely available in remote villages.

4. Education and Wage Labor

In general Tsimane men and women have little to no schooling: The adult literacy rate is low at 18% and only 5% of adults aged 18—25 are high school graduates (most of these are men) (Gurven, Fuerstenberg, et al., 2016). This has improved in recent years but the quality of schools remains low and inversely related to distance to town. Women usually receive less education than men and are less fluent in Spanish. The difference in Spanish fluency is partly due to women being less likely to have regular contact with non-Tsimane or visit town than men. Men require some Spanish fluency for wage labor, which is commonly with logging companies, ranches or anthropology and health projects. There are extremely few wage labor opportunities for women, leaving women highly dependent on male relatives and husbands for money. Money is needed to access town (e.g. travel costs and paying for room and board), and thus most healthcare. Despite medical care being free at the hospital and several medical outposts, the cost of travel is often the limiting factor. Consequently women are less likely to travel or seek medical care on their own, and women and children have poorer health than men (Gurven et al., 2007).

This within and among village variation in fertility, morbidity, mortality, and access to healthcare makes the Tsimane an ideal population to study the relationships among childhood and current experiences of mortality, perceptions of morbidity and mortality, and reproductive preferences and outcomes.

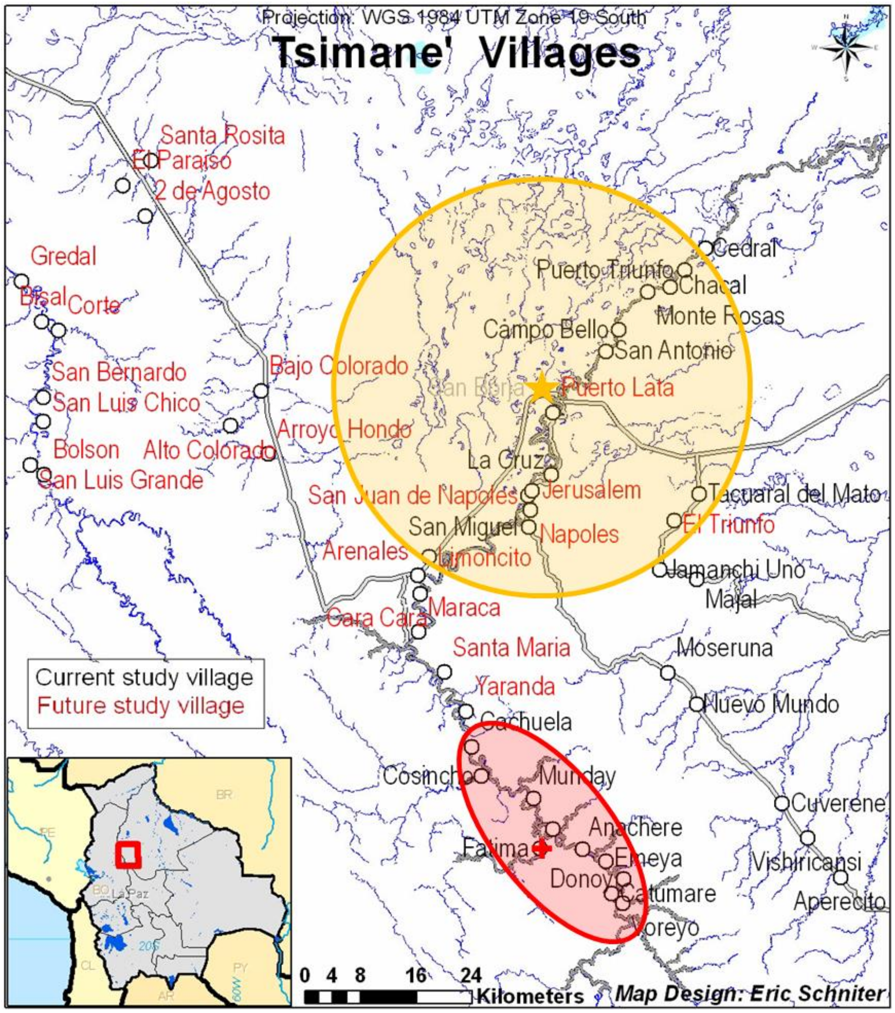


Figure 3. Map of Tsimane villages associated with the Tsimane Health and Life History Project. The yellow circle denotes villages within 30km of San Borja, the nearby town marked by a yellow star. Residents of these villages have easier, almost year round access to San Borja, and the healthcare available there. The red cross near the bottom of the map denotes Fatima, where there is a Catholic Mission and Health Post. The red oval denotes villages that receive visits from Fatima based doctors year-round and whose residents have relatively easy access to Fatima throughout the year. Map designed by Eric Schniter.

B. Study I: The effect of experiences and perceptions of morbidity and mortality on women's reproductive preferences

1. Hypotheses and Prediction

Our hypothesis is that cues of local morbidity and mortality shape perceptions of environmental harshness in ways that can influence reproductive decisions. Here we explore whether experiences of sibling and own infant mortality, and perceptions of morbidity and mortality, influence reproductive preferences. The reproductive preferences of interest are preferred age at first birth, interbirth interval, and completed fertility. Our general prediction is that when women experience high sibling or infant mortality, or perceive their local morbidity or mortality to be high, they will have reproductive preferences that encourage high fertility. This will manifest as younger preferred age at first birth, shorter preferred interbirth intervals and larger preferred family sizes among women who have experienced greater sibling mortality or infant mortality among their own children compared to other women. Women who perceive morbidity and mortality to be high, should also have younger preferred ages of first birth, shorter preferred interbirth intervals and larger preferred family sizes than women who perceive morbidity and mortality to be low. The relationship between women's perceptions of morbidity and mortality, and their actual health and experiences with mortality are also discussed.

2. Methods

The data discussed here is taken from a larger project. From July-September 2010 and April-August 2011, 166 Tsimane women, aged 13 to 85, from seven Tsimane communities were interviewed one to three times in private. The main project consisted of three surveys that could be taken in one sitting or at different times. The data presented here is from the third survey (N = 124).

The seven villages (Figure 4) vary in distance to town, accessibility of healthcare (difficulty in traveling to town and access to an in village health post or trained health provider), quality of school, morbidity and mortality (Gurven, 2012a; Gurven et al., 2007; Kaplan et al., 2015), and fertility rate (Kaplan et al., 2015; McAllister et al., 2012). The characteristics of each village, relevant to this paper, are summarized in Table 1.

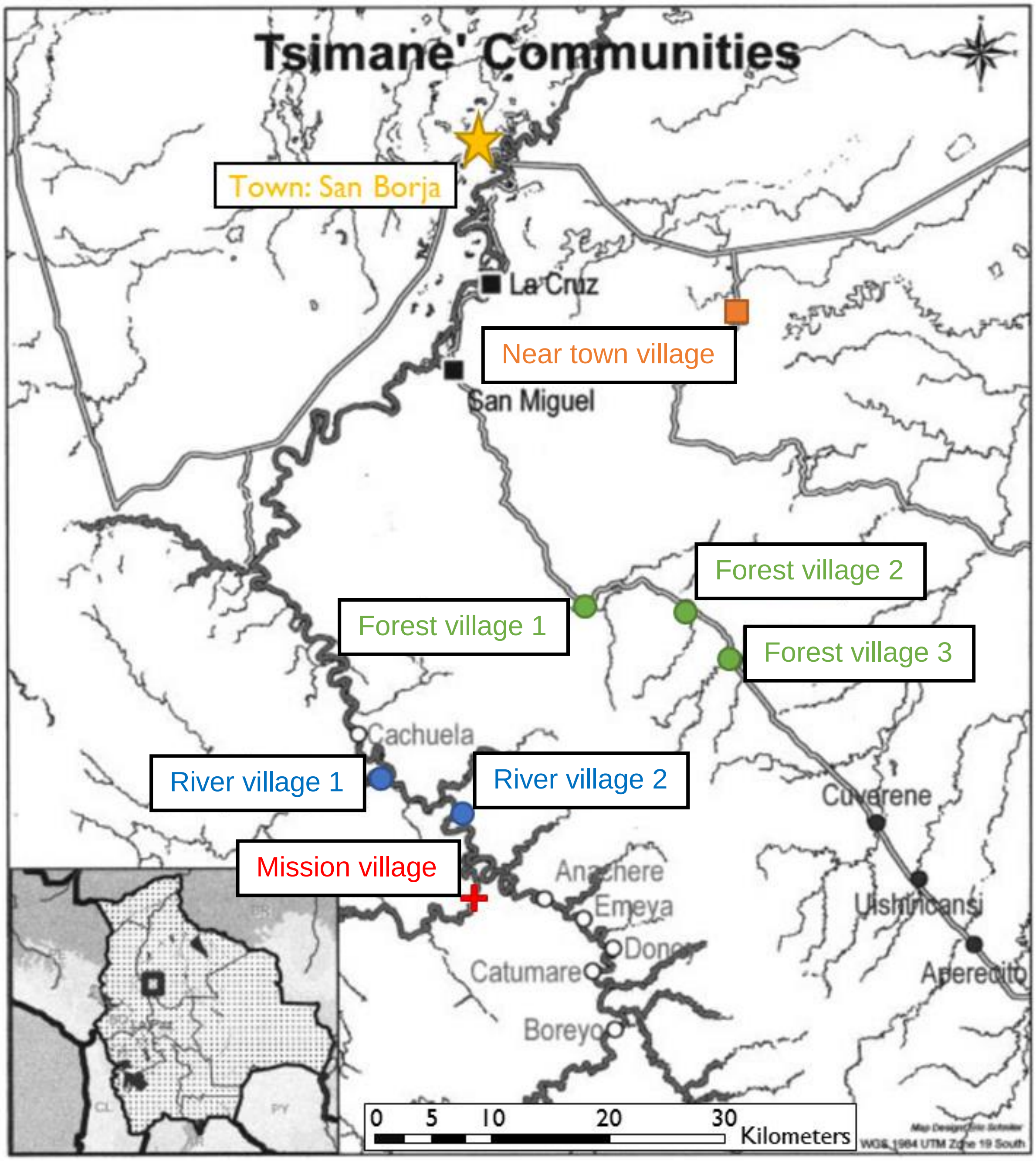


Figure 4. Map showing the Tsimane communities where reproductive preferences and perceptions of mortality and morbidity were collected from 127 Tsimane women. The dark grey lines are rivers and tributaries, and the pale grey lines are roads. The yellow star marks the nearest town, San Borja. The orange square marks a village near San Borja that is highly market integrated. The green dots mark the forest communities, which are the least market integrated. The blue dots mark the riverine villages, and the red cross marks a village with a Catholic Mission, a health post and a relatively extensive school system. Map adapted from Gurven et al (2007).

Table 1. Village level characteristics. Demographic indicators for Beni Department and San Borja are also shown. NA means non-applicable and "-" means the data is unavailable.

						Distance to San Borja (km)		Village health care[b]			Education[c]				Mortality rates per 1,000 individuals[e]					
Community	Pop. Size	Number of women	Number of women interviewed	Coverage (% of adult women interviewed)	Year int.	Crow flies	Travel route	Medic	Pharmacy	Age stratified	High School	Teacher absence	TFR[d]	<1	1-4	5-14	15-39	40-59	60+
Beni Department[a]	430,593		NA		2011	NA	NA	NA	NA	NA	NA	NA	3.6	35.8	-	-	-	-	-
Town																			
San Borja[a]	~24,610		NA		NA	0	0	Hospital	Many	Yes	Yes	Rare	-	-	-	-	-	-	-
Near town	-		-		NA	-	-	-	-	-	-	-	9.46	85	8	1	2	10	36
Near town village	537	108	39	36%	2011	27.46	29.38	Tsimane	Limited	Yes	Yes	Rare	-	-	-	-	-	-	-
Mission	-				NA	-	-	-	-	-	-	-	9.89	111	8	5	4	4	42
Mission village	642	158	39	25%	2011	65.45	107.21	Doctors	Yes	Yes	Yes	Some	-	-	-	-	-	-	-
Riverine	-		-		NA	-	-	-	-	-	-	-	9.87	147	18	5	6	8	30
River village 1	292	65	27	41%	2011	55.84	84.97	Tsimane	Limited	Some	No	Some	-	-	-	-	-	-	-
River village 2	111	16	16	100%	2011	58.05	93.28	Tsimane	Limited	No	No	Often	-	-	-	-	-	-	-
Forest	-		-		NA	-	-	-	-	-	-	-	8.62	171	17	4	7	7	33
Forest village 1	58	17	16	94%	2010	24.76	30.56	No	No	No	No	Often	-	-	-	-	-	-	-
Forest village 2	151	25	10	40%	2010	44.43	61.25	No	No	No	No	Often	-	-	-	-	-	-	-
Forest village 3	125	19	19	100%	2010	68.25	50.31	No	No	No	No	Often	-	-	-	-	-	-	-
Tsimane Total	**~15,000**		**166**		-	-	-	-	-	-	-	-	**9.1**	**126**	**12**	**4**	**5**	**7**	**34**

a. The data for Beni Department and San Borja are taken from the (Instituto Nacional de Estandística de Bolivia, 2011).

b. Village health care refers to whether a health care provider resides in the village and who they are. Tsimane means a Tsimane health worker lives in the village. However, their training and medical supplies are limited and rarely updated. Doctors refers to the Spanish and Bolivian professional medics that reside in the Mission village for most of the year. For Pharmacy, limited means the Tsimane health worker keeps a stock of basic anti-biotics and the DepoProvera Injection; however, accessing these can have socio-political and economic ramifications for a patient. For example, women in Village$_{R2}$ who wish to use the DepoProvera injection must make three jatata roofing tiles to pay to the Tsimane health worker. This is touted as a way to remind the women to return in every three months. But, it signals to others that the woman is using DepoProvera. Also, making the jatata roofing tile be a temporal burden, limiting a woman's time spent in other activities such as gathering food and maintaining the home. Both taking the DepoProvera injection and being perceived to not be caring for your home properly can lead to malicious gossip about a woman.

c. Education refers to whether the quality of the schooling available in a village. Age stratified means there are multiple different classes allowing students to be split by age and/or ability. High School refers to the level of education available. Teacher absence refers to how often the teacher(s) are absent from the school. Absences are usually last multiple consecutive weeks.

d. TFR (Total fertility rate) was calculated from retrospective data collected by the Tsimane Health and Life History Project. See Appendix Table 1 for details.

e. Mortality rates are for 1990-2002 and are taken from Gurven et al (2007).

All homes within a one hour walking distance of a village center were visited, and all women residents 13 years or older were invited to participate. For women that expressed an interest in participating, a date, time and location for the interview were agreed upon. Approximately 41% of women from these seven communities were interviewed. Among villages, the percent of women interviewed varied from 25% in the largest village (pop. > 600) to 100% in smaller villages (pop. ≤ 125). Difference in coverage are due to many houses in larger villages being outside the one hour travel radius from the village center, and women traveling further from home to get to their agricultural fields and thus being less available. Also, in two villages ~50% of the women left one week after the community meeting for a mass fishing expedition that lasted several weeks. Women who were not interviewed were random with respect to age, parity, and other variables of interest (Appendix 1 Table 2). Table 3 shows the fertility and mortality statistics for this subsample.

On the third survey, women were asked a series of questions about their perceptions of infant, child, and maternal morbidity and mortality in their community. For morbidity women were asked how often they thought children in their community were sick (rarely, sometimes, always), how often they thought they are sick (never, rarely, sometimes, often, always), and how often they thought they were sick compared to other women in their community (less, the same, more). For mortality women were asked how often they thought infants and young children (aged 1 to 5) died in their community (rarely, sometimes, often). Women's number of siblings that died in infancy and number of own children that died in infancy, fertility-at-interview, educational attainment, Spanish fluency, and age-at-interview were taken from reproductive histories and other interviews collected by the Tsimane Health and Life History Project, and updated by LSM in 2010 and 2011. Table 3 describes the independent variables used in our models and how these were coded.

Table 2. Fertility and mortality means ±SD and rates for Tsimane women in this sample.

Trait	N	Mean ±SD	Minimum	Maximum
Mean ±SD age at interview	166	32.45 ±14.80	13	84.86
Mean ±SD distance to town (km)[a]	166	48.29 ±15.52	0.00	66.17
Fertility				
Mean ±SD age at first birth	166	17.48 ±2.44	12.64	25.97
Mean ±SD interbirth interval after miscarriage	80	20.85 ±9.90	10.24	63.72
Mean ±SD interbirth interval after live birth	130	29.36 ±8.43	16.16	55.73
Mean ±SD number of pregnancies	166	5.76 ±4.43	0	16
Total number of pregnancies	166	1002		
Mortality				
Fetal mortality rate	166	5.7%		
Infant mortality rate	166	11.2%		
Child mortality rate 1-5 years	166	2.7%		
Child mortality rate 6-15 years	166	0.9%		
Education				
Mean ±SD spoken Spanish fluency[b]	166	0.57 ±0.65	0	2
Mean ±SD Spanish literacy[c]	166	0.51 ±0.66	0	2
Mean ±SD years of schooling	92	2.08 ±3.48	0	16
Mean ±SD final school grade	166	2.06 ±2.51	0	10.33
Mean ±SD ego education factor	166	0.00 ±1.00	-1.34	1.05

a. Distance is as the crow flies. This does not account for the type of terrain a Tsimane must cross to get to town or the actual route a Tsimane may be forced to take. For example, Tsimane living in riverine communities must take a more winding route to get to town due to the meandering of the rivers they travel.
b. Spanish fluency is measured on a three-point scale, with 0 indicating no fluency, 1 a little fluency, and 2 fluent.
c. Spanish literacy is measured on a three-point scale, with 0 indicating unable to read or write in Spanish, 1 indicating some ability to read or write in Spanish, and 2 that a person writes and reads well in Spanish.

Women's reproductive preferences for themselves (preferred interbirth interval in years), and for their sons and daughters (preferred age at first birth in years and whether they wanted their children to have few or many children) were collected. Women were also asked open-ended questions about why they had these reproductive preferences: (1) Why is that a good age for your daughter (or son) to have their first child?; (2) Why is that a good amount of time to wait before having another child? Why not less time? Why not more time?; (3) Why do you think your daughter (or son) should have that many children? How many children should women in your village have? Why should women not have fewer children? Why should women not have more children?. This qualitative data is used here to help interpret Tsimane women's goals and reasoning. All analyses were done using general linear models and binary logistic regression in IBM SPSS (V.23).

Table 3. List and description of independent variables. Under coding the numbers in parentheses are the sample size for that group.

Independent variable	N	Type	Description	Coding
Women's general characteristics				
Distance of resident community from town	124	continuous	Distance from center of community to center of nearest town as the crow flies. In km.	NA
Education factor	124	continuous	Principle components analysis of women's years of schooling, Spanish fluency and literacy. Ranges from -1.34 (woman that never attended school, does not speak Spanish and is non-literate) to 1.05 (woman attended school, is very fluent in Spanish and is literate).	NA
Age	124	continuous	Women's age at time of interview	NA
Women's reproduction and infant mortality				
Age at first birth	109	continuous	For women that have given birth, the year they were born subtracted from the year they gave birth.	
Mean interbirth interval (IBI)	71	continuous	Mean time between births in years for women with known dates of birth for children at both ends of the intervals.	
Parity-for-age	124	continuous	Studentized residuals of women's parity for her age or by 45 for post-menopausal women. Ranges from -4.42 (nulliparous post-menopausal woman) and -3.69 (uniparous 43 year old woman) to 2.72 (37 year old woman with 14 live births).	
Infant-mortality-for-parity	124	continuous	Studentized residual of a woman's total infant deaths for her parity. Ranges from -1.77 (13 live births and no infant deaths) to 4.91 (13 live births and six infant deaths).	NA
Sibship infant mortality				
Sibship size	119	continuous	Number of live births a woman's mother had before the women's age at first birth. Or before a woman turned 25 for nulliparous women.	
Mother's infant deaths-for-parity	119	continuous	Studentized residual of number of siblings that died in infancy before a woman's first birth by her mother's number of live births before a woman's first birth. Capped at 25 years for nulliparous women. Ranges from -1.41 (woman with 15 siblings that all survived infancy) to 3.61 (woman with twelve siblings, six died in infancy).	
Perceived morbidity			Women's responses to:	
local child morbidity	123	binary	"How often are children sick in this community?"	0=sometimes (81), 1=always (42)
own morbidity	123	categorical	"How often are you too sick to do your daily chores and care for your family?"	1=rarely (36), 2=sometimes (48), 3=often (39)
own morbidity compared to other women	123	categorical	"Are you sick less often, about the same amount, or more often than other women in this community?"	1=less (46), 2=same (44), 3=more (33)
Perceived mortality				
local infant mortality	124	binary	"How often do babies, children just born to 1 year old, die in this community?"	0=never (47), 1=sometimes (77)
local child mortality	124	binary	"How often do children, children from 1 year old to 15 years, die in this community?"	0=never (90), 1=sometimes (34)

3. Results

3.1. Experienced mortality

Tsimane women vary regionally in their parity-for-age, and number of fetal losses, and infant and child deaths-for-parity (Table 4 shows how infant, child and adult mortality rates varied by region between 1990 and 2002 across a large Tsimane sample). Of the Tsimane women sampled here, women living in the *Forest* region and *Near Town* had more fetal losses (miscarriages and stillbirths) than women from the *Riverine* region or the *Mission* (Table 4). However, infant mortality was higher in the *Mission* and *Riverine* regions, and young (1-5 years old) child mortality was higher in the *Riverine* villages. There was no association between region and older (6-15 years old) child mortality.

Table 4. Mortality rates by geographic region. Fixed effects for generalized linear models predicting the association between geographic region of residence and fetal, infant or child mortality. There was no association between region and pregnancy-for-age-and-age2 (F(3,150) = 0.89, p =.45), for live births-for-age-and-age2 (F(3,150) = 0.56, p =.64) despite higher fetal loss in Near Town and Forest women, or for children surviving passed age one for age and age2 (F(3,150) = 1.12, p =.34) despite fewer infant deaths Near Town.

				Own child mortality[a,b,e]								
	Siblings dead in infancy[c]			Foetal losses[d]			Infants (< 1 year)		Young child (1-5)		Older child (6-15)	
Region	N	%	β (SE)	N	%	β (SE)	%	β (SE)	%	β (SE)	%	β (SE)
Near Town	33	12.58	-0.68 (0.37)†	37	8.52	-0.17 (0.14)	9.87	RC	1.79	RC	1.35	RC
Mission	26	15.03	-0.73 (0.39)†	34	3.45	-0.27 (0.14)*	13.36	0.39 (0.22)*	2.16	0.01 (0.10)	0.43	0.03 (0.06)
Riverine	38	10.78	-0.75 (0.35)*	35	2.27	-0.45(0.14)***	10.91	0.48 (0.22)†	5.00	0.17 (0.10)†	1.82	0.03 (0.05)
Forest	32	22.02	RC	40	9.87	RC	13.30	0.26 (0.21)	2.58	0.09 (0.09)	0.43	-0.03 (0.05)
Total	129	13.27	-	146	6.06	-	11.89	-	2.86	-	0.99	-

† p <.10, * p <.05, ** p <.01, *** p <.001

a. The reference category is marked by RC.

b. Pregnancies-for-age-and-age^2 positively associated with number of fetal losses (β (SE) = 0.23 (0.05), p <.001). live births-for-age-and-age^2 positively associated with number of infant deaths (β (SE) = 0.36 (0.08), p <.001), number of early (1-5 years old) child deaths (β (SE) = 0.09 (0.03), p = 0.01), but not for number of later (6-15 years old) child deaths (β (SE) = 0.01 (0.02), p =.73).

c. Siblings dead in infancy is number of siblings that died in infancy. Note, near town women have larger sibships: Mean ±SD sibship size near town = 9.64 ±2.99, Mission = 7.42 ±3.21, riverine = 8.79 ±3.14, forest = 8.66 ±2.72. Sibship size, women's age and age^2 included in the model.

d. Fetal losses include all miscarriages (including induced) and stillbirths. Pregnancies-for-age-and-age^2 included in model.

e. Parity-for-age-and-age^2 included in models.

3.2. Experienced mortality versus perceived mortality and morbidity.

Women whose mothers had more infant deaths-for-parity (controlling for older sibling deaths-for-parity, mother's ID, ego's distance to town, age, and age^2) perceived infant mortality in their community to be low compared to women whose mothers had few infant deaths-for-parity (r = -0.221, p = .019). While older sibling deaths had weak to no correlation with perceived infant or child mortality rate now: Women who had more siblings die when the siblings were between 1 to 5 years old trended toward lower perceived infant mortality rates now (r = -0.164, p = .082); number of sibling deaths of siblings aged 6 to 15 years old at death showed no association with perceived infant or child mortality now. These weak negative correlations may be due to women recognizing that infant and child mortality has decreased since their childhoods. Also, given the wide age range of subjects' sibling deaths in infancy may have been recent or decades ago: The mean ±SD time since a sibling died in infancy was 25.62 ±14.26, with a minimum of 2 years before interview (woman was 20 years old at interview) and a maximum of 60 years ago (woman was 56 years old at interview, sibling died before woman was born).

Women's experiences with their own infant and child mortality are not correlated with their perceptions of infant and child mortality: Women who had more of their infants or children die given their parity, and controlling for their age, age^2 and distance to town, did not perceive infant (*Pearson's* r = 0.02, p = .83) or child mortality (r = -0.02, p = .85) to be higher than women who had fewer of their infants or children die. Perceived child morbidity also showed no correlation with women's infant and child deaths-for-parity: Women who had high infant and child deaths for their parity did not perceive community children to be sick more often (r = 0.04, p = .64), or their own children to be comparatively sicklier than other children in their community (r = -0.002, p = .99), compared to other women.

However, again given the wide age range of women sampled here, women may have lost an infant or child recently or decades ago: Mean ±SD years since infant death was 12.58 ±14.88, with a minimum of infant died a few months before interview (eight women aged between 16 and 32 years), and a maximum of 47 years before interview (two women aged 61 and 76 years).

The region women reside in was associated with women's perceptions of infant and child mortality (Table 6). *Mission, Riverine* and *Forest* women were less likely to say babies sometimes die in this village, compared to never die, than women in the *Near Town* village. However, despite infant mortality usually being lower *Near Town* than in the other regions (Table 4), there was a spike in infant mortality in that village in the twelve months prior to the interviews and lower than average infant mortality in the other villages sampled here (infant mortality rate *near town* = 12.5%, *Mission* = 10.5%, *riverine* = 0%, and *forest* = 7.1%), suggesting mortality risk is inaccurately perceived or strongly influenced by recent rather than long-term observations. Child mortality was mis-perceived with women in the *Forest* region all saying children never die in their villages, and in the *Riverine* region women were less likely to say children sometimes die in their village than *Mission* or *Near Town* women (Table 6). —child mortality is higher in *Riverine* and *Forest* villages (Table *4*), and a two-year-old child died in the *forest* region 9 months prior to interviews.

Table 5. Regional variation in perceptions of infant and child mortality. Odds Ratios (OR) with 95% Wald Confidence Intervals (CI) shown for women's perceptions of infant and child mortality. For "children sometimes die in this village" the Forest region was removed from the analysis as all women said children in their village never died.

Parameter	Babies sometimes die in this village			Children sometimes die in this village		
	OR	95% Wald CI Lower	Upper	OR	95% Wald CI Lower	Upper
Region						
Near Town	1	-	-	1	-	-
Mission	.35†	.11	1.15	.87	.31	2.43
Riverine	.23*	.07	.75	.15**	.04	.58
Forest	.11**	.03	.49	-	-	-
Parity-for-age-and-age^2	.69†	.46	1.03	1.00	.61	1.63
Child deaths-for-parity	1.16	.79	1.69	1.21	.70	2.09
Education factor	1.02	.63	1.67	1.15	.62	2.12
Intercept	4.93***	1.94	12.53	.81	.37	1.75

† *p* <.10, * *p* <.05, ** *p* <.01, *** *p* <.001

Taken together these findings suggest that among adult Tsimane women personal experiences of mortality may not influence perceptions of mortality and morbidity risk. Instead recent village level infant and child mortality may influence perceived mortality risk. Consequently, below we compare the relationships between reproductive preferences, and both experienced and perceived mortality to elucidate whether experiences or perceptions influence reproductive decisions making.

Adding consistency to the data, we find positive associations among women's perceptions of morbidity and mortality (controlling for distance to town, education factor, parity-for-age-and-age^2, and child deaths-for-parity). For example, women that perceived local child morbidity to be high were 2.75 times more likely to perceive themselves to often be sick, 9.12 times more likely to perceive themselves to be sick more often than other women in their community, and 3.14 times more likely to perceive infants to often die in their community (Table 6 Model 1, 2 and 3 respectively). For additional relationships among women's perceptions of morbidity and mortality see Appendix 1 Tables 3 through 6.

Table 6. The positive associations between perceived child morbidity[a], and perceived own morbidity and infant mortality measures. Odds Ratios (OR) with 95% Wald Confidence Intervals (CI) shown for women's perceptions of mortality and morbidity.

Parameter	Model 1			Model 2			Model 3			Model 4		
		95% Wald CI			95% Wald CI			95% Wald CI			95% Wald CI	
	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Women's characteristics												
Distance to town	1.01	0.98	1.03	0.98	0.96	1.01	1.01	0.98	1.03	1.00	0.98	1.03
Education factor	0.96	0.63	1.46	0.98	0.65	1.48	0.86	0.58	1.29	0.94	0.63	1.41
Parity-for-age-and-age2	1.26	0.83	1.89	1.21	0.80	1.81	1.14	0.76	1.72	1.05	0.71	1.53
Child-deaths-for-parity	1.00	0.67	1.49	1.08	0.72	1.63	1.02	0.69	1.50	1.04	0.72	1.51
Perceived morbidity												
Own morbidity[b]												
Sometimes sick	**0.30***	0.10	0.88	-	-	-	-	-	-	-	-	-
Often sick	**2.75***	1.04	7.25	-	-	-	-	-	-	-	-	-
Own morbidity compared to others[c]												
Sick less often than others	-	-	-	**2.87***	0.97	8.49	-	-	-	-	-	-
Sick more often than others	-	-	-	**9.12*****	2.79	29.84	-	-	-	-	-	-
Perceived mortality												
Local infant mortality[d]	-	-	-	-	-	-	**3.14***	1.30	7.57	-	-	-
Local child mortality[e]	-	-	-	-	-	-	-	-	-	1.01	0.42	2.43
Constant	0.41			1.11			0.16*			0.44		

† *p* < 0.10, * *p* <.05, ** *p* <.01, *** *p* <.001
a. Perceived local child morbidity is for local children are often sick (N=39) compared to only sometimes sick (N=78).
b. Perceived own morbidity is for sometimes sick (N=48) or often sick (N=38) compared to rarely sick (N=36).
c. Perceived own morbidity compared to others is for ego sick less (N=45) or more (N=32) often than others compared to equally (N=44) often as others.
d. Perceived local infant mortality is for infants often die (N=72) compared to only sometimes die (N=47).
e. Perceived local child mortality is for children often die (N=33) in this community compared to only sometimes die (N=90).

3.3. Women's experiences and perceptions of mortality and morbidity, and their reproductive preferences

First, we explored whether women's experiences of infant mortality influence their reproductive preferences. A woman's childhood exposure to infant mortality was taken as number of infant sibling deaths given her mother's parity (mother's infant deaths-for-parity), and a woman's adult exposure to infant mortality as the number of her children who died in infancy given her parity (infant deaths-for-parity). Women's perceptions of morbidity and mortality were added to models that considered direct experience with mortality (see Table 6 for how these were measured and coded). The reproductive preferences, dependent variables, explored are preferred age at first birth and completed family size for sons and daughters, and preferred interbirth interval for self.

3.3.1. Experiences and perceptions of mortality and morbidity, and preferred age at first birth for sons and daughters

Controlling for women's age, education and distance from town, Tsimane women preferred older ages of first birth for their sons (N = 119) than daughters (N = 122): mean ±standard error is 22.55 ±0.33 for sons, and 20.13 ±0.27 for daughters (paired t-test, $t = 7.73$, $df = 118$, $p < 0.001$). General linear mixed methods were used to assess how own children's infant deaths, sibling infant deaths and perceptions of morbidity and mortality influence women's preferred age at first birth for their sons and daughters. For sons and daughters 21 models were assessed (Appendix 1 Table 7 for sons and Table 8 for daughters). The base model included distance of women's resident community to town (km), education, and age as controls (see Table 7– Model 1 for sons and Table 9 – Model 1 for daughters). For sons, the base model explained 10.3% of the variance in preferred age at first birth ($R^2 = 0.103$, $F(3,115) = 4.408$, $p = 0.006$) and for daughters only 1.4% of the variance ($R^2 = 0.014$, $F(3,118) = 0.561$, $p = 0.642$). To these base models variables associated with women's infant deaths, sibling infant deaths (random effect of having the same mother included in these models), and morbidity and mortality perceptions were added. The best model is the model with the lowest AIC_C and highest Akaike weight (w_i) values. However, models with $w_i > 0.2$ are considered to have strong support (Anderson & Burnham, 2002). The models for sons are shown in Table 7, and for daughters in Table 9 (see Appendix 1 Table 7 and Table 8, respectively, for why these models were selected).

Women living further from town preferred younger ages at first birth for their sons (Table 7– Model 1), but no association for their daughters (Table 9– Model 1). Older women preferred older ages at first birth for their sons (Table 7– Model 1); however, women's age had no association with preferred age at first birth for daughters (Table 9 – Model 1). Women's own age at first birth had no association with preferred age at first birth for their children. Parity-for-age had no association with preferred age at first birth for sons (Table 7– Model 4 and 6). Conversely, women with higher parity-for-age preferred earlier ages at first birth for daughters than women with lower parity-for-age when infant deaths-for-parity was in the model (Table 9 – Model 6).

Women's experiences of their own children's infant deaths bore no association with preferred age at first birth for sons (Table 7, Model 6), but was associated with older preferred ages at first birth for daughters (Table 9- Model 6). This may be related to younger ages at first birth being associated with poor maternal and child outcomes: A common quote from women across all communities was, *"[If a woman is too young] her body is not ready and she will get sick.*" This is supported by 55% of women stating that they would have preferred an older age at first birth for themselves than their actual age at first birth--commonly because they felt their body was not ready and their first pregnancy was very difficult--while only 21% of women would have preferred a younger age at first birth and 24% were happy with their age at first birth. Controlling for women's residential community distance from town and their ages at interview, there was no association between women's age at first birth and their opinions on whether they had their first birth at a good age (est. marginal mean ±SE: too young = 17.28±0.29, good age = 17.76±0.42, too old = 17.91±0.45). Women's experiences of sibling infant deaths had no association with their preferred age at first birth for their sons (Table 7– Models 15) or their daughters (Table 9 - Model 16).

Women's perceptions of child and their own morbidity, and infant mortality also had no association with their preferred ages at first birth for sons and daughters. However, women who perceived that children often die in their community preferred sons to be approximately two years older, and daughters one year older, when they had their first child than women who perceived that children only sometimes die in their community (Table 10).

Table 7. Preferred age of first birth for sons. Parentheses is the standard deviation. See Appendix 1 Table 7 for the other models explored. Note that model 15 includes a random effect of women having the same mother, and Model 4 has a lower N and consequently their AICC should not be directly compared to the other models.

	Model 1 Base model	Model 4 Own reproduction	Model 6 Own Infant deaths	Model 15 Sibling infant deaths	Model 12 Mortality perceptions
Intercept	24.008 (1.160)***	23.165 (2.465)***	24.095 (1.157)***	23.498 (1.809)***	23.462 (1.153)***
Distance to town	-0.067 (0.021)***	-0.055 (0.021)**	-0.069 (0.021)***	-0.068 (0.023)**	-0.062 (0.020)**
Education factor	0.090 (0.342)	0.095 (0.351)	0.074 (0.341)	-0.050 (0.363)	-0.126 (0.345)
Age	0.055 (0.023)*	0.035 (0.026)	0.055 (0.023)*	0.057 (0.025)*	0.050 (0.022)*
Own reproduction and infant mortality					
Age at first birth	-	0.055 (0.149)	-	-	-
Parity-for-age	-	0.467 (0.400)	0.069 (0.370)	-	-
Infant deaths-for-parity	-	-	0.338 (0.316)	-	-
Sibship infant mortality					
Mother's parity	-	-	-	0.057 (0.111)	-
Mother's infant deaths-for-parity	-	-	-	0.158 (0.341)	-
Perceived morbidity and mortality					
Local child mortality[a]	-	-	-	-	1.754 (0.711)*
N	119	106	119	117	119
R^2	0.103	0.081	0.113	-	0.147
AIC_C	641.465	571.357	644.632	643.492	637.747

† $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived local child mortality is for children often die (N=33) compared to only sometimes die (N=86).

Table 8. Preferred age at first birth for daughters. See Appendix 1 Table 8 for the other models explored. Note that model 16 includes a random effect of women having the same mother and Model 4 has a smaller N, consequently their AICC should not be directly compared to the other models.

	Model 1 Base model	Model 4 Own reproduction	Model 6 Own Infant deaths	Model 16 Sibling infant deaths	Model 12 Mortality perceptions
Intercept	20.402 (0.963)***	21.215 (2.130)***	20.602 (1.025)***	20.328 (1.330)***	20.218 (0.924)***
Distance to town (km)	-0.014 (0.017)	-0.009 (0.019)	-0.019 (0.016)	-0.022 (0.016)	-0.016 (0.016)
Education factor	-0.213 (0.281)	-0.225 (0.307)	-0.260 (0.273)	-0.200 (0.265)	-0.378 (0.274)
Age	0.012 (0.018)	0.018 (0.021)	0.018 (0.019)	0.007 (0.020)	0.013 (0.017)
Own reproduction and infant mortality					
Age at first birth	-	-0.070 (0.126)	-	-	-
Parity-for-age	-	-0.357 (0.323)	-0.467 (0.272)†	-0.498 (0.264)†	-0.469 (0.268)†
Infant deaths-for-parity	-		0.852 (0.250)***	0.712 (0.254)**	0.859 (0.247)***
Sibship infant mortality					
Mother's parity	-	-	-	0.073 (0.079)	-
Mother's infant deaths-for-parity	-	-	-	0.366 (0.256)	-
Perceived morbidity and mortality	-	-	-	-	-
Local child mortality	-	-	-	-	0.980 (0.565)†
N	122	109	122	119	122
R^2	0.014	0.023	0.108	-	0.129
AIC_C	612.201	559.248	606.757	587.932	603.819

† $p < .10$, * $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived own morbidity compared to others is for ego sick less (N=45) or more (N=32) often than others compared to equally (N=44) often as others.

b. Perceived local infant mortality is for infants often die (N=72) compared to only sometimes die (N=47).

c. Perceived local child mortality is for children often die (N=31) compared to only sometimes die (N=88).

Table 9. Preferred age at first birth for sons and daughters by whether women perceived children to often or only sometimes die in their community. Estimated marginal means (EMM) of women's preferred ages of first birth for sons and daughters are for sons from Table 7–Model 12 and for daughters from Table 9–Model 12.

Perceived child mortality	Sons			Daughters		
	EMM ±SE	95% CI	*p*	EMM ±SE	95% CI	*p*
Children in this community						
Sometimes die	22.07 ±0.36	21.36 – 22.78	0.014	19.86 ±0.29	19.30 – 20.42	0.097
Often die	23.82 ±0.60	22.65 – 24.99		20.78 ±0.47	19.87 – 21.70	

3.3.2. Experiences and perceptions of mortality and morbidity, and preferred interbirth intervals for women

Although preferred interbirth intervals (IBI) were similar to actual IBI (mean ±SD for preferred IBI for self (N = 124) = 2.46 ±0.92 years, and for actual IBI after a live birth (N = 71) = 2.45 ±0.70 years, paired t-test: $t = 1.36$, $df = 70$, $p = .179$), there was no correlation between women's preferred and actual IBI (controlling for women's distance from town, education, age, and parity-for-age: Pearson's $r = 0.062$, $df = 65$, $p = .616$).

General linear mixed models were used to assess how own children's infant deaths, sibling infant deaths and perceptions of morbidity and mortality influence women's preferred IBI. Twenty models were assessed. The base model includes women's distance from town, education and age. Models were also run with parous women's actual mean IBI included; however, this reduced the sample size by 32%. Women's distance from town, education, age, parity-for-age, infant deaths-for-parity, and sibling infant deaths had no association with their preferred IBI (Table 10- Model 1,3,6, 15, and Appendix 1 Table 9).

Of the perceived morbidity variables, women who perceived themselves to be sick more often than other women had preferred IBIs ~6 months shorter than women who perceived themselves to be sick equally or less often than other women (Table 10; Model 9): Estimated marginal means ±standard error for more often = 1.95 ±0.19, equally often = 2.54 ±0.15, and less often = 2.67 ±0.15. Conversely, perceived local infant and child mortality had no association with women's preferred IBI (Appendix 1 Table 9 Models 18 and 19).

Globally, shorter IBIs are associated with poorer maternal and infant health outcomes (Agustin Conde-Agudelo et al., 2005; Agustín Conde-Agudelo, Rosas-Bermudez, Castaño, & Norton, 2012). However, among Tsimane women asked "Why do you prefer to wait that long before having another child?" (N = 123), concerns about poor maternal health were only raised by 17.1% of women, and poor health or survival outcomes for the previous child by 6.5% of women and for the new child by 2.4% of women. The main concerns for Tsimane women were that the previous child be independent (34.1%), allowing the mother to work in the fields (30.9%), in the home (27.6%) and/or at tasks associated with making money (21.2%).

Focused interviews suggest that women believe that they have limited control over their IBIs. Among a sub-sample of parous women (N = 40), 85.0% said that when they first had sex after giving birth was decided by their husbands, and 15% that it was decided by both their husbands and themselves. Among a larger subsample of parous women (N = 60) 68.3% said how long they waited until having another child was up to their husbands, 30.0% that it was decided by both themselves and their husbands, and only one woman said that she decided when she had another baby.

Furthermore, the expectation of short IBIs pervades Tsimane culture. When asked "After giving birth, how long should Tsimane women wait before having another baby?", the mean ±standard deviation was 2.41 ±1.00 years, with 55% of women saying 2 years and 29% of women 3 years (N = 120).

Table 10. Preferred interbirth interval. See Appendix 1 Table 9 for the other models explored. Note that model 15 includes a random effect of women having the same mother and consequently their AICC should not be directly compared to the other models shown here.

	Model 1 Base model	Model 3 Own reproduction	Model 6 Own Infant deaths	Model 15 Sibling infant deaths	Model 9 Morbidity perceptions
Intercept	2.382 (0.329)***	1.911 (0.698)**	2.368 (0.330)***	2.495 (0.513)***	1.610 (0.466)***
Distance to town	-0.002 (0.006)	0.0003 (0.007)	-0.001 (0.006)	-0.001 (0.006)	-0.001 (0.006)
Education factor	0.041 (0.107)	0.014 (0.137)	0.048 (0.107)	0.081 (0.112)	0.097 (0.104)
Age	0.005 (0.006)	0.006 (0.009)	0.004 (0.006)	0.002 (0.007)	0.011 (0.007)
Own reproduction and infant mortality					
Mean interbirth interval	-	0.120 (0.243)	-	-	-
Parity-for-age	-	0.025 (0.147)	0.008 (0.101)	-	-
Infant deaths-for-parity	-	-	-0.076 (0.107)	-	-
Sibship infant mortality					
Mother's parity	-	-	-	-0.011 (0.031)	-
Mother's infant deaths-for-parity	-	-	-	-0.101 (0.103)	-
Perceived morbidity and mortality					
Own morbidity compared to others[a]					
Perceive self to be sick less often than others	-	-	-	-	0.714 (0.250)**
Perceive self to be sick equally often as others	-	-	-	-	0.592 (0.257)*
N	105	71	105	101	104
R^2	0.007	0.011	0.013	-	0.067
AIC_C	289.151	205.854	293.194	298.989	281.269

* $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived own morbidity compared to others is for ego sick less (N=45) or equally (N=32) often than others compared to more (N=44) often than others.

3.3.3. Experiences and perceptions of mortality and morbidity, and preferred family size for sons and daughters

Tsimane women preferred both their sons and daughters to have few children: Only 21% of women wanted their sons to have many children and 18.5% their daughters. When asked "How many children does a family with few children have?" and "How many children does a family with many children have?", the mean ±SD was 4.04 ±2.39 for few and 10.17 ±4.07 for many.

Logistic regression was used to assess the effects of perceived morbidity and mortality on whether women preferred their children to have few or many children. The base model shows a negative association between women's education and suggests that more educated women (education factor = 1) are 15.28 times more likely to prefer their sons have few children (Table 11), and 12.39 times more likely to prefer their daughters have few children (Table 12), than less educated women (education factor = -1). This may be related to more educated Tsimane women often being more market integrated and concerned about the monetary cost of a large family: 44.7% of highly educated Tsimane women (education factor > 1, N = 47) stated that an issue with having a large family was not having enough money, compared to only 26.9% of highly uneducated Tsimane women (education factor < -1, N = 26). However, distance to town and age, which are generally negatively associated with market integration, bore no association with women's preferred family sizes for their children.

Women with high parity for their age (parity-for-age = 1.5, e.g. 36 year old woman with eleven live births) trended toward being 5.42 times more likely to prefer their sons have many children compared to women with low parity-for-age (parity-for-age = -1.5, e.g. 36 year old woman with four live births) (Table 14). However, parity-for-age was unrelated to the preferred number of children for their daughters (Appendix 1 Table 11). Women's experiences of infant deaths-for-parity had no relationship with their preferred number of children for sons or daughters (Appendix 1 Table 10 and 11 respectively). However, women who had relatively many siblings die in infancy given their mothers' parities (mother's infant deaths-for-parity = 1, e.g. 15 siblings, three died in infancy) were 3.79 times more likely to prefer their daughters to have more children than women who had few siblings die in infancy (mother's infant deaths-for-parity = -1, e.g. twelve siblings, all survived infancy) (Table 14).

Table 11. Preference for sons to have many (vs. few) children based on women's distance from town, education factor and age**.**

Woman's characteristics	*B*	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.023	.383	1.710	1	.191	.976	.941	1.012
Education factor	-1.363	.019	18.588	1	< .001	.256	.138	.475
Age	-.081	.316	1.075	1	.300	.982	.949	1.016
Constant	.142	.017	.021	1	.885	1.152		

Note: Model is significant $\chi^2(3) = 25.273$, $p = < .001$, explained 29.6% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 76.3% of cases. Sensitivity was 26.9%, specificity was 90.2%, the positive (many children) and negative (few children) predicted values were 43.8% and 81.4% respectively.

Table 12. Preference for daughters to have many (vs. few) children based on women's distance from town, education factor and age.

Woman's characteristics	*B*	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.024	.019	1.409	1	.235	.978	.942	1.015
Education factor	-1.258	.325	15.017	1	< .001	.284	.150	.537
Age	-.017	.018	.890	1	.345	.982	.950	1.018
Constant	-.193	1.1019	.036	1	.850	1.152		

Note: Model is significant $\chi^2(3) = 20.015$, $p = < .001$, explained 24.4% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 80.3% of cases. Sensitivity was 8.7%, specificity was 97.0%, the positive (many children) and negative (few children) predicted values were 40.0% and 82.1% respectively.

Table 13. Preference for sons to have many (vs. few) children based on women's distance from town, education factor, age and parity-for-age.

Woman's characteristics	*B*	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.023	.019	1.483	1	.223	.978	.943	1.014
Education factor	-1.429	.331	18.652	1	.000	.240	.125	.458
Age	-.024	.018	1.684	1	.194	.977	.942	1.012
Parity-for-age	.564	.316	3.180	1	.075	1.757	.946	3.264
Constant	.137	1.000	.019	1	.891	1.146	.162	8.136

Note: Model is significant $\chi^2(3) = 28.703$, $p = < .001$, explained 33.1% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 78.0% of cases. Sensitivity was 26.9%, specificity was 92.4%, the positive (many children) and negative (few children) predicted values were 50.0% and 81.7% respectively.

Table 14. Preference for daughters to have many (vs. few) children based on women's distance from town, education factor and age, parity-for-age, sibship size, and mother's infant deaths-for-parity. Mixed general linear models used with a random effect of women's mothers to control for shared sibship. However, this random effect is not necessary for the model as it does not account for a significant amount of the heterogeneity among the women sampled here (Wald test: z = 1.25, p = .21).

Woman's characteristics	*B*	S.E.	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-0.019	.025	.446	.981	.935	1.030
Education factor	-1.253	.389	.002	.286	.132	.618
Age	-.015	.025	.541	.985	.938	1.035
Parity-for-age	-.135	.311	.665	.874	.472	1.617
Sibship size	.009	.105	.933	1.009	.819	1.243
Mother's infant deaths-for-parity	.666	.312	.035	1.947	1.049	3.612
Constant	-.608	1.791	.735	.544	0.016	18.936

Note: Model is significant $F(6,108)$, $p = 0.007$, and correctly classified 90.8% of cases. Sensitivity was 65.4%, specificity was 96.6%, the positive (many children) and negative (few children) predicted values were 85.0% and 90.5% respectively.

Women's perceptions of local morbidity rates may influence their preferred family sizes for their sons but not their daughters (Appendix 1 Table 10 and 11 respectively). Women who perceived that children were often sick in their community trended toward being 2.71 times more likely to prefer their sons have many children than women who perceived children to only sometimes be sick (Table 15). While, compared to women that thought they were sick equally often as other women, women who thought they were sick less often were 3.93 times, and women who thought they were sick more often 4.07 times, more likely to prefer many children for their sons (Table 16). Morbidity perceptions had no association with family size preferences for daughters.

Table 15. Preference for sons to have many (vs. few) children based on women's distance from town, education factor, age, parity-for-age, and perceptions of child morbidity in their community.

	B	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.016	.019	.744	1	.388	.984	.947	1.021
Education factor	-1.408	.332	17.982	1	.000	.245	.128	.469
Age	-.028	.020	2.060	1	.151	.972	.935	1.010
Parity-for-age	.602	.328	3.356	1	.067	1.825	.959	3.475
Perceived local child morbidity								
Children are often sick[a]	.998	.554	3.247	1	.072	2.713	.916	8.034
Constant	-.358	1.073	.111	1	.739	.699		

a. Perceived local child morbidity is for children are often sick compared to only sometimes sick.
Note: Model is significant $\chi^2(5) = 31.621$, $p < .001$, explained 36.2% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 85.5% of cases. Sensitivity was 50.0%, specificity was 95.6%, the positive (many children) and negative (few children) predicted values were 76.5% and 87.0% respectively.

Table 16. Preference for sons to have many (vs. few) children based on women's distance from town, education factor, age, parity-for-age, and perceptions of their own morbidity compared to other women in their community.

	B	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.033	.020	2.692	1	.101	.968	.930	1.006
Education factor	-1.391	.329	17.833	1	.000	.249	.130	.475
Age	-.026	.020	1.589	1	.207	.975	.936	1.014
Parity-for-age	.762	.363	4.406	1	.036	2.143	1.052	4.366
Perceived own morbidity compared to others[a]								
Sick more often	1.368	.686	3.980	1	.046	3.929	1.024	15.069
Sick less often	1.403	.760	3.410	1	.065	4.066	.917	18.025
Constant	-.194	1.077	.032	1	.857	.824		

a. Perceived own morbidity compared to others is for sick more often or less often than other women compared to equally often.
Note: Model is significant $\chi^2(6) = 34.027$, $p < .001$, explained 38.6% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 86.3% of cases. Sensitivity was 57.7%, specificity was 94.5%, the positive (many children) and negative (few children) predicted values were 75.0% and 88.7% respectively.

Perception of local infant mortality rates had no association with whether women wanted few or many children for their sons and daughters (Appendix 1 Table 10 Model 7 and Table 11 Model 7 respectively). However, women who perceived children to often die in their community trended toward being 3.39 times more likely to prefer their sons to have many children (Table 17), but 7.17 times more likely to prefer their daughters to have few children (Table 18).

Table 17. Preference for sons to have many (vs. few) children based on women's distance to town, education factor, age, parity-for-age, and perceptions of child mortality in her community.

	B	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.022	.019	1.302	1	.254	.979	.943	1.016
Education factor	-1.710	.395	18.737	1	.000	.181	.083	.392
Age	-.033	.020	2.787	1	.095	.968	.931	1.006
Parity-for-age	.695	.349	3.967	1	.046	2.003	1.011	3.969
Perceived local child mortality								
Children often die[a]	1.220	.685	3.176	1	.075	3.387	.885	12.958
Constant	-.086	1.007	.007	1	.932	.917		

a. Perceived local child morbidity is for children are often sick compared to only sometimes sick.
Note: Model trends toward being significant $\chi^2(5) = 32.023$, $p < .001$, explained 36.5% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 79.7%% of cases. Sensitivity was 34.5%, specificity was 91.3%, the positive (many children) and negative (few children) predicted values were 55.6% and 84.0% respectively.

Table 18. Preference for daughters to have many (vs. few) children based on women's distance to town, education factor, age, parity-for-age, and perceptions of child mortality in her community.

	B	S.E.	Wald	*df*	*p*	Odds Ratio	95% CI for Odds Ratio Lower	Upper
Distance to town	-.023	.020	1.337	1	.247	.978	.941	1.016
Education factor	-1.098	.328	11.210	1	.001	.334	.175	.634
Age	-.009	.018	.269	1	.604	.991	.956	1.027
Parity-for-age	.054	.255	.046	1	.831	1.056	.641	1.739
Perceived local child mortality								
Children often die[a]	-1.969	1.074	3.363	1	.067	.140	.017	1.145
Constant	-.092	1.074	.007	1	.932	.912		

a. Perceived local child morbidity is for children are often sick compared to only sometimes sick.
Note: Model is significant $\chi^2(5) = 25.316$, $p < .001$, explained 30.2% (Nagelkerke R^2) of the variance in whether women wanted their sons to have few or many children, and correctly classified 82.8% of cases. Sensitivity was 21.7%, specificity was 97.0%, the positive (many children) and negative (few children) predicted values were 62.5% and 84.2% respectively.

4. Discussion

We expected experienced high infant mortality rates, and perceptions of high child and own morbidity rates, or infant and child mortality rates, to be associated with preferences for a faster life history pace – i.e. younger ages at first birth, shorter interbirth intervals and larger family sizes. However our results were more mixed than expected, and suggest that Tsimane women have distinct preferences for sons versus daughters that are influenced by different factors. Table 20 summarizes the findings.

Table 19. Summary of findings. The relationships among the independent variables explored here and Tsimane women's reproductive preferences are shown. Dots indicate a variable that had no significant relationship with women's reproductive preferences, and NA indicates not tested for that reproductive preference. In parentheses is whether the relationship is associated with a fast or slow life history pace. Green indicates the relationship is as expected given life history theory. Red indicates that the relationship does not follow simple predictions based on life history theory.

	Reproductive Preferences				
	Age at first birth for own children		Interbirth interval	Number of children for own children	
Independent variables	Sons	Daughters	for self	Sons	Daughters
Women's reproduction and infant mortality					
Age at first birth	•	•	NA	NA	NA
Interbirth interval	NA	NA	•	NA	NA
High parity-for-age	•	younger (fast)	•	many (fast)	•
High infant-mortality-for-parity	•	older (slow)	•	•	•
Sibship infant mortality					
Large sibship size	•	•	•	•	•
High mother's infant deaths-for-parity	•	•	•	•	many (fast)
Perceived morbidity					
local child morbidity high	•	•	•	many (fast)	•
own morbidity high	•	•	•	•	•
own morbidity higher than other women's	•	•	shorter (fast)	many (fast)	•
Perceived mortality					
local infant mortality high	•	•	•	•	•
local child mortality high	older (slow)	older (slow)	•	many (fast)	few (slow)

4.1. Experienced mortality

Experiences of own children dying in infancy and siblings dying in infancy had no association with reproductive preferences for sons, or preferred interbirth interval for self. However, women's experiences of their own children's infant mortality encouraged preferences for delayed reproduction in daughters, while their childhood experiences of infant mortality (siblings dying in infancy) encouraged preferences for larger family sizes for daughters.

The former may be to encourage daughters to delay reproduction until they are fully grown – given the association between poor maternal health and younger ages at first birth--

and with their husbands to have accrued sufficient resources to support a family. While the latter may suggest that experiences of sibling infant deaths have such a strong effect on women, encouraging preferences for a fast life history pace, that later stimuli indicating improved conditions and lower infant mortality rates may be ineffective. This is somewhat surprising though, women should be attuned to the infant mortality rates their daughters are likely to face rather than those faced two generations ago. Tsimane women are aware that family sizes have changed over the decades—75.0% of the women sampled here said that Tsimane have fewer children now than in the past—and that infant mortality rates have declined: "*Today some women have 14 to 16 children. In the past this was more common but often the children died when they were little… Women know more about having children now. Women are more careful now and many use contraceptives or* [abortive medicinal] *plants*". 60 year old woman, with 7 children (one died in infancy), from the *Mission* community.

4.2. Perceived morbidity

We found no effect of perceived child and own morbidity on reproductive preferences for daughters. However, perceived high child and own morbidity was found, as expected, to encourage a preference for a faster life history pace for self and sons (preferred shorter IBI for self and many children for sons). Unexpectedly, low perceived morbidity was also associated with a preference of many children for sons. If a woman associates her current perceived condition with her sons' future conditions, favouring sons taking advantage of their positive energy balance by having many children may have socio-political advantages. Among the Tsimane kinship size is positively associated with socio-political power and resource access. However, this is tempered by the locality of kin, as married sons are more likely to reside long-term near their parents, this may help explain why we observed no effect of perceived good condition (sick less often than others) on family size preference for daughters. Additionally, women who perceive themselves to be in better condition may believe they will be healthy enough to provide allocare for any grandchildren reducing the burden of a large family for her sons who reside near her.

4.3. Perceived mortality

Perceived infant mortality had no association with women's reproductive preferences for self or children. This is surprising given the association between experiences of infant mortality and women's reproductive preferences for daughters. However, high perceived child mortality was found to encourage preferences for a slow life history pace in daughters (preferred older ages at first birth and few children), which was unexpected. If infant mortality is considered outside the control of the mother (which is likely as most infants die of infectious diseases and are less likely to be taken to a health provider), but child mortality is associated with parenting ability and nutritional status of a child, then preferring fewer children for daughters may be beneficial. It may help ensure daughters' children survive under stressful conditions as in small families each child receives more attention and resources. It also may protect the daughter from bereavement. Among the Tsimane, large families are associated with poorer health and survival for mother and children: "*It is difficult for a woman to have many children. Children are sick a lot and you always have to worry they are going to die.*" 21 year old mother of two living in the *near town* community.

High perceived child mortality was found to have a mixed relationship with reproductive preferences for sons (preferred older ages at first birth but many children). However, an older age at first birth for sons does not preclude sons having many children, especially if delaying the first birth allows sons to accrue resources that enable them to better provide for a larger family.

The differences in preferred family sizes for sons versus daughters may be related to five aspects of Tsimane culture. First, sons' abilities to accrue resources are known, while the abilities of sons-in-law are unknown. Women may not want to risk resource stress for their daughters if their sons-in-law are poor providers, but are confident in their own sons' abilities to feed their potential families. "*My sons will know how to work hard and make good [agricultural] fields. My sons can afford many children. My daughters' husbands may not know how to do these things very well, but my sons will do them well."* 56 year old woman, with 11 children (1 died in infancy and 2 in early childhood), from a *riverine* community.

Second, favouring many children for sons may help ensure enough grandchildren to help care for a woman in her old age. There is a general sense among the Tsimane that married daughters do not decide where they live in the long-term and must go where their husbands go; and that it is the duty of sons to help their aging parents. Consequently, sons may be more likely to reside near their aging parents and share resources with their aging parents. "*I do not want many grandchildren. I just want enough grandchildren to help. My sons can have more children [than my daughters] as they will have better [agricultural] fields and more food for their families. My daughters' husbands may be lazy and have bad fields. Also, sons help their parents more. Daughters must help their parents-in-law*". 27 year old mother of two from a *riverine* community.

Third, Tsimane women may have an inherent preference for smaller family sizes for daughters that is harder to shift upwards than family preferences for sons. This may be due to women being more empathetic towards their daughters as their reproductive experiences have greater overlap: Sons will not bear the burden of childbirth including the pain or risk of death, and will not be the main care takers of children.

Fourth, Tsimane women undervalue daughters-in-law, and thus may not account for any risk or hardship their sons' high fertility may cause their daughters-in-law. "*I want my sons to have many children so I have many grandchildren. My daughters should have few children as large families are difficult to care for. My daughters will use plants like buisi to wait between births. I do not care if my daughter-in-law has a hard life caring for my many grandchildren."* 24 year old woman with three children from the *Mission* community.

Lastly, the cost to a woman of a high fertility daughter's death is potentially much higher than the cost of a higher fertility daughters-in-law's death. If a daughter-in-law dies a son is likely to remarry. His parents, or his former in-laws, may be tasked with raising any surviving children, but the son is likely to provide resources and support. If a son-in-law dies a daughter usually returns to her parents' home with her children and is seen as a burden. If she remarries she will likely leave any children from her previous union with her parents and move away with her new husband. Although she may wish to provide resources and support to any children from a previous union, her ability to independently accrue resources or money is limited. Most resources she has access to, and how they are allotted, are controlled by her new husband. This leaves her aging parents with the heavy burden of young dependents.

In summary, our findings suggest that women's experiences of mortality, and perceptions of local morbidity and mortality rates may help shape their reproductive preferences. However, the directionality of the relationships is not always as expected. Also, sons and daughters are seen as distinct reproducers for whom women have often divergent reproductive preferences. This may suggest women have distinct preferences for sons versus daughters that are influenced by different factors and/or through different pathways.

Women's preferences for daughters may be especially influenced by greater empathy for what reproduction will entail for daughters. Furthermore, assuming an association between reproductive preferences for children and children's reproductive outcomes, high fertility among the Tsimane may be a response to observations and experiences of illness, rather than death. However, these relationships are likely complicated by healthcare inequality, and perceived modifiability of health.

A major issue with this work, however, is that preferences for children may be unrelated to a woman's own life history strategy. Women may instead be basing their preferences for children on the potential sociopolitical and security in old age gains of having many grandchildren; or alternatively a desire to protect, especially their daughters, from the hardships and risks of high fertility. Consequently a woman may herself have a fast life history pace but have completely unrelated reproductive preferences for her children.

4.4. Additional independent variables: Distance, education and age

Among Tsimane women there is a general preference for older ages at first birth than what women actually have, and smaller family sizes. The evaluation of three general characteristics of Tsimane women help elucidate these trends: women's distance of resident community from town, education and age. Women living closer to town and older women preferred older ages at first birth for sons, and more educated women preferred smaller family sizes for sons and daughters. These relationships are unsurprising. Over the last decade local health professionals, the Bolivian government, and charitable organizations have funded education and outreach programs that highlight the benefits of smaller families and discuss how to achieve them. For example, the *near town* community is visited by health workers who espouse family planning and smaller family size, as well as improved sanitation and the benefits of vaccinations, several times a year. The *Mission* community and the neighbouring *riverine* communities have regular group meetings where family planning is discussed. The Catholic nuns advocate natural methods of family planning, but in general encourage smaller families, delayed ages at first birth (and prolonged education for men and women), and longer interbirth intervals. Physicians and nurses at the local health clinic and Tsimane health workers residing in these communities encourage the use of and provide contraceptives. The remote *forest* communities are, however, rarely visited by health professionals and receive limited family planning advice or education. For example, 77% of women from the *near town* community and 65% from the *riverine communities* reported they had attended a meeting where family planning was discussed in the last year; while, none of the women from the *forest* communities reported attending such a meeting in the past 12 months.

Furthermore, *forest* women's access to and knowledge of contraceptives is more limited. For several months every year they are cut off from town due to heavy rains. During this time the logging roads they live along, and the associated bridges, are not maintained by the logging companies, making the roads impassable to vehicles. *Forest* women desperate to get to town can walk, but this is a difficult multi-day journey, and women with multiple young dependents that would have difficulty accompanying them are especially unlikely to travel during this time. A year round travel restriction for Tsimane women, that is rigorously adhered to in more traditional villages, further limits *forest* women's access to contraceptives: Tsimane women should only travel outside their community when accompanied by a male, adult relative (an older, female relative may be acceptable in some instances). When asked how often they had visited town unaccompanied by a male, adult relative, 96.0% of *forest* women said never, 97.2% of *riverine* women, and 77.4% of *Mission* women, compared to 40.0% of *near town* women. In the *near town* community women are relatively more autonomous and have easier access to town (a ~45 minute taxi ride with taxis arriving several times a day to the village centre).

The family planning and health programs provided to the Tsimane come on the heels of programs aimed at the national population that, in the Beni Department where the Tsimane reside, successfully dropped the total fertility rate from 5.9 in 1989 to 3.8 in 2008 (http://dhsprogram.com). The declining fertility of their neighbours has not gone unnoticed by the Tsimane; and for Tsimane who desire a more market integrated life copying their neighbours' lower fertility may be an attractive option. "*I would like to live in town. [But,] it is expensive. You have to buy all your food in town as there is no farmland or animals to hunt. And, you have to pay for everything, even your home. So, you cannot have many children in town. Having many children is expensive. Like the [non-Tsimane] town women you have to work and read, write and speak Spanish well to have a good life in town. So, I have to get more education and a good job in town. Then I can live in town and like the [non-Tsimane] town women have a few babies.*" 21 year old, nulliparous, married woman living near town.

C. Study II: The effects of infant sibling deaths on women's reproductive outcomes

1. Hypotheses and Predictions

In humans high infant mortality rates are associated with earlier ages at first birth, shorter inter-birth intervals, and higher total fertility – a fast life history pace (Angeles, 2009; Low et al., 2008, 2013; McAllister et al., 2016; Placek & Quinlan, 2012). In Study I we found mixed support for this. However, we did fine that women who had many siblings die in infancy, given their sibship size, preferred their daughters to have many children, suggesting a preference for a fast life history pace. Here we explore the durability of this relationship by examining the effects of infant sibling deaths, and in addition the timing of these deaths, on women's actual life history paces. The variables of interest are: age at first birth, rate of progression to second birth, and parity-for-age. We predict that high rates of infant mortality in a woman's sibship encourages a faster life history pace. This will manifest as younger age at first birth, faster progression to second birth and higher parity-for-age among women who experienced many infant sibling deaths compared to women who experienced few infant sibling deaths.

We also predict that the timing of infant sibling deaths is important. Störmer and Lummaa (2014) found that all sibling deaths had a greater effect than just deaths of younger siblings. Here we compare the deaths of siblings a woman did not know – older siblings that died in infancy -- versus the deaths of siblings she knew – younger siblings that died in infancy. The former may change women's parents' behaviour, as suggested by Störmer and Lummaa (2014), creating a more stressful rearing environment that all children in the family experience, and encouraging a faster life history. However, we expect internalizations about environmental harshness to be stronger when considering deaths of children born before ego, as then ego would have only ever experienced the post-death, more stressful rearing environment. However, this may be masked as, with the deaths of younger siblings, women may in addition experience bereavement, which has also been associated with encouraging a faster life history (G. V. Pepper & Nettle, 2013). Experiencing bereavement may shift them to a faster life history strategy despite their less stressful pre-sibling death rearing environment.

Lastly we predict that sibship size impacts the effect of a sibling death on a woman's life history pace: a single sibling death in a small sibship may have a greater effect than a single sibling death in a large sibship. In a small sibship a single sibling death releases a relatively larger proportion of resources for division among fewer surviving, competing siblings. This may slow a woman’s life history pace and encourage greater investment in self before reproduction. However, the emotional toll of a sibling death in a small sibship may be greater and this may encourage a faster life history pace. Alternatively, infant mortality rates may not be indicative of mortality risk at older ages. Infant mortality may cue women that infants need more investment if they are to survive, and thus encourage a slower life history pace.

2. Methods

2.1. Data Collection

The reproductive and mortality data presented here were collected by the Tsimane Health and Life History Project (THLHP) from 2002 to 2012. The demographic interviews and methods used to collect reproductive and mortality data, and ascribe ages are described in detail in Gurven et al (2007).

To summarize, reproductive and mortality events from 2002 to 2012 were ascribed from retrospective reproductive histories of interviewees that included questions about sibling and own children deaths. These reproductive and mortality events were then cross-validated with those of interviewees’ parents, children, siblings and spouses, where possible, to assign estimated order of and timing of events. Reproductive and mortality events were further collected and verified from 2006 to 2012 during the bi-annual censuses and medical checkups performed by the Tsimane Health and Life History Project. Age at reproductive event, including age at first birth, were assigned from parent and child years of birth. It is not taboo to talk about neonate or infant deaths among the Tsimane, although these events may be under-reported due to recall bias or being unknown by corroborating family members absent at time of event.

The main independent variable of Study I is number of sibling infant deaths up to a woman's age at first birth. An infant death is counted as any live birth resulting in death within the first year of life. Here only women whose mothers had complete reproductive histories were considered (N = 1089). Women whose mothers had miscarriages or births with unknown event times were removed from this study. This allowed us to know women's mothers' ages at first birth and parities, women's birth order, and number of sibling deaths before and after their birth, and the age siblings died.

We examine only infant deaths within the natal family as Tsimane women live relatively cloistered lives until marriage. Consequently, the family is the most important group a woman has membership in and in which her close relationships exist. This makes the family her most important point of reference for environmental cues during childhood. Childhood family environment is likely a good predictor of the future environmental conditions a woman will face. Also, the loss of a sibling, even an infant sibling, disrupts established family patterns and leads to readjustments in women's surviving siblings' and parents' behaviours, further impacting the family environment (Uhlenberg, 1980).

2.2. Data Analysis

To assess the effect of sibling deaths on women's progression to first birth and rate of progression to second birth Cox regression and Kaplan-Meier survival estimates from Cox proportional hazard models were run in R. For all analyses a frailty term was added to the model to account for women from the same mother (shared sibship). In analyses of progression to first birth (N=1089), right-censored observations (n=434) of nulliparous women are included in the risk set. Ages at first birth were calculated as the mother's year of birth subtracted from first born child's year of birth. For nulliparous women age was taken as age at last interview. . Women with first births or miscarriages at unknown ages were not included.

Models of progression to second birth (N = 711) consider the interbirth interval between the first and second births (only calculated for women with full dates of birth known for both children), with n=171 right-censored observations of women who had not had a second child by the time of most recent interview. Women with no follow up record after their first birth were removed. Only progression to second birth was considered for ease of analysis: (1) interbirth intervals are not consistent over the life course and commonly increase with parity; and (2) for higher parities probability of another birth declines for innumerable reasons, including greater chance of impaired fecundity and among the Tsimane greater acceptance of use of abortives.

To assess the effects of sibling deaths on women's reproductive rates, taken as parity-for-age, general linear mixed methods (GLMMs) were run in IBM SPSS version 23 with a random effect for shared sibship (same mother). Parity-for-age was taken as the studentized residuals from a linear regression of women's parity against their age (N = 608). Women with incomplete reproductive histories were removed (n= 481).

3. Results

3.1. Descriptive Statistics

The women discussed herein were born between 1978 and 1998 (Table 20). 45% of women lived within 30km of town as the crow flies, and 30% of women lived 50km or further, and subsequently have extremely limited access to town. Most women were uneducated and spoke little Spanish (Table 20). The mean birth order was ~4th, and sibship size by age at first birth or last interview was ~8, and the mean sibling infant deaths was ~1.

Controlling for sibship size and distance to town, we found no association between women's year of birth and number of infant sibling deaths ($B(3,1085) = -0.034$, $p = .23$), despite secular declines in mortality. This may be due to the limited age range of the women discussed here (15 to 35 years in 2013). We also found a weak negative trend between year of birth and sibship size ($B(2,1086) = -0.052$, $p = .09$).

Table 20. Descriptive statistics of the women sampled here.

Characteristic	N	Mean ±SD	Minimum	Maximum
Year of birth	1089	1990.34 ±5.76	1978	1998
Distance to town (km)[a]	1089	38.45 ±20.84	5.63	82.15
Spoken Spanish fluency[b]	915	0.93 ±0.77	0	2
Spanish literacy[c]	914	0.81 ±0.76	0	2
Years of schooling	157	2.58 ±2.94	0	16
Final school grade	916	3.09 ±2.40	0	14
Birth order	1089	4.28 ±2.97	1	15
Sibship size	1089	7.75 ±2.89	1	18
Older siblings	1089	3.16 ±2.87	0	13
Younger siblings	1089	4.59 ±2.36	0	13
Infant sibling deaths	1089	0.84 ±1.17	0	7
Older sibling infant deaths	1089	0.37 ±0.79	0	6
Younger sibling infant deaths	1089	0.47 ±0.82	0	5
Age at first birth (among parous women only)	655	17.26 ±2.27	12	25
Inter-birth interval (among multiparous women only)	419	26.56 ±11.48	8	73
Parity-for-age (among parous women only)	608	0.00 ±1.00	-2.77	3.56

a. Distance is as the crow flies. This does not account for the type of terrain a Tsimane must cross to get to town or the actual route a Tsimane may be forced to take. For example, Tsimane living in riverine communities must take a more widning route to get to town due to the meandering of the rivers they travel.
b. Spanish fluency is measured on a three point scale, with 0 indicating no fluency, 1 a little fluency, and 2 fluent.
c. Spanish literacy is measured on a three point scale, with 0 indicating unable to read or write in Spanish, 1 indicating some ability to read or write in Spanish, and 2 that a person writes and reads well in Spanish.

3.2. Experiences of sibling infant mortality and progression to first birth

The number of siblings that died in infancy (here forth infant sibling deaths) before a woman's first birth bore no association with her age at first birth (Table 22– Model 1). However, comparing infant sibling deaths by when they occurred, we find the deaths of older siblings in infancy delay first birth (Table 22– Model 2; Figure 5A), while the deaths of younger siblings in infancy accelerate first birth (Table 22 - Model 3; Figure 5B): Median age at first birth for women who had no siblings die in infancy before or after their birth was

~19 years, compared to ~20 years for women who had 3 sibling die in infancy before their birth, and ~18 years for women who had 3 sibling die in infancy after their birth.

Comparing infant sibling deaths before and after a woman was born, we find that both have a significant effect on her age at first birth and maintain their directionality (Table 22 – Model 4). Given their opposing directionality, they may counter each other, explaining the lack of effect of sibling infant deaths when all siblings are considered (Table 22 - Model 1).

Looking at the effects of sibship size on women’s age at first birth, we found that women with larger sibships (woman’s mother’s parity at woman’s first birth) are likely to start reproducing at older ages than women with smaller sibships (Figure 6; Table 22: Model 1): Median age at first birth for women with few siblings (3 siblings) was ~18 years, compared to ~20 years for women with many siblings (13 siblings).

We also observe a significant interaction term: sibship size*sibling deaths (Table 22). Having many older or younger siblings mutes the effects of their deaths in infancy on women’s ages at first birth. For example, when women have many older siblings, older siblings’ dying in infancy encourages younger rather than older ages at first birth (Appendix 1 Figure 1); and, when women have many younger siblings, younger siblings dying in infancy encourages older ages at first birth rather than younger (Appendix 1 Figure 2).

Lastly, we find that women living closer to town have younger ages at first birth: Per 50km closer to town the median age at first birth declines by ~1 year (Figure 7). There may also be a secular increase in age at first birth (Table 22 – Model 1).

Table 21. Women's progression to first birth as function of proportion of siblings that died in infancy, and whether siblings died in infancy before or after a woman was born. Models are Cox regressions (N=1089, Events = 655). Frailty term for family membership (N = 565) included in model to control for same family environment among sisters. Sibship size is for siblings born in the time period for which sibling deaths are counted.

Variable	Model 1 β (S.E.)	Model 2 β (S.E.)	Model 3 β (S.E.)	Model 4 β (S.E.)
Distance to town (km)	-0.004 (0.002)*	-0.004 (0.002)†	-0.004 (0.002)*	-0.004 (0.002)*
Age	0.432 (0.079)***	0.442 (0.079)***	0.423 (0.076)***	0.423 (0.076)***
Age^2	-0.007 (0.002)***	-0.007 (0.002)***	-0.007 (0.001)***	-0.007 (0.001)***
Birth Order	0.032 (0.019)	-	-0.025 (0.015)	-
Mother's age at first birth	-0.017 (0.017)	-0.011 (0.017)	-0.017 (0.015)	-0.014 (0.015)
All siblings born before woman's first birth				
Number of siblings	-0.054 (0.023)*	-	-	-
Number of dead siblings	0.164 (0.172)	-	-	-
Siblings*sibling deaths	-0.010 (0.017)	-	-	-
Before woman born				
Number of siblings	-	-0.014 (0.017)	-	**-0.037 (0.017)***
Number of dead siblings	-	**-0.276 (0.149)†**	-	**-0.331 (0.144)***
Siblings*sibling deaths	-	**0.045 (0.023)***	-	**0.051 (0.022)***
After woman born				
Number of siblings	-	-	-0.037 (0.021)	**-0.038 (0.021)†**
Number of dead siblings	-	-	**0.345 (0.127)****	**0.385 (0.129)****
Siblings*sibling deaths	-	-	**-0.043 (0.019)***	**-0.048 (0.019)***
Frailty term (mother's ID)	NS	NS	NS	NS
AICc	61.963 7882.277	59.713 7886.230	11.778 7889.656	13.101 7887.870
McFadden pseudo R^2	0.028	0.027	0.015	0.015

† p <.10, * p <.05, ** p <.01, *** p <.001

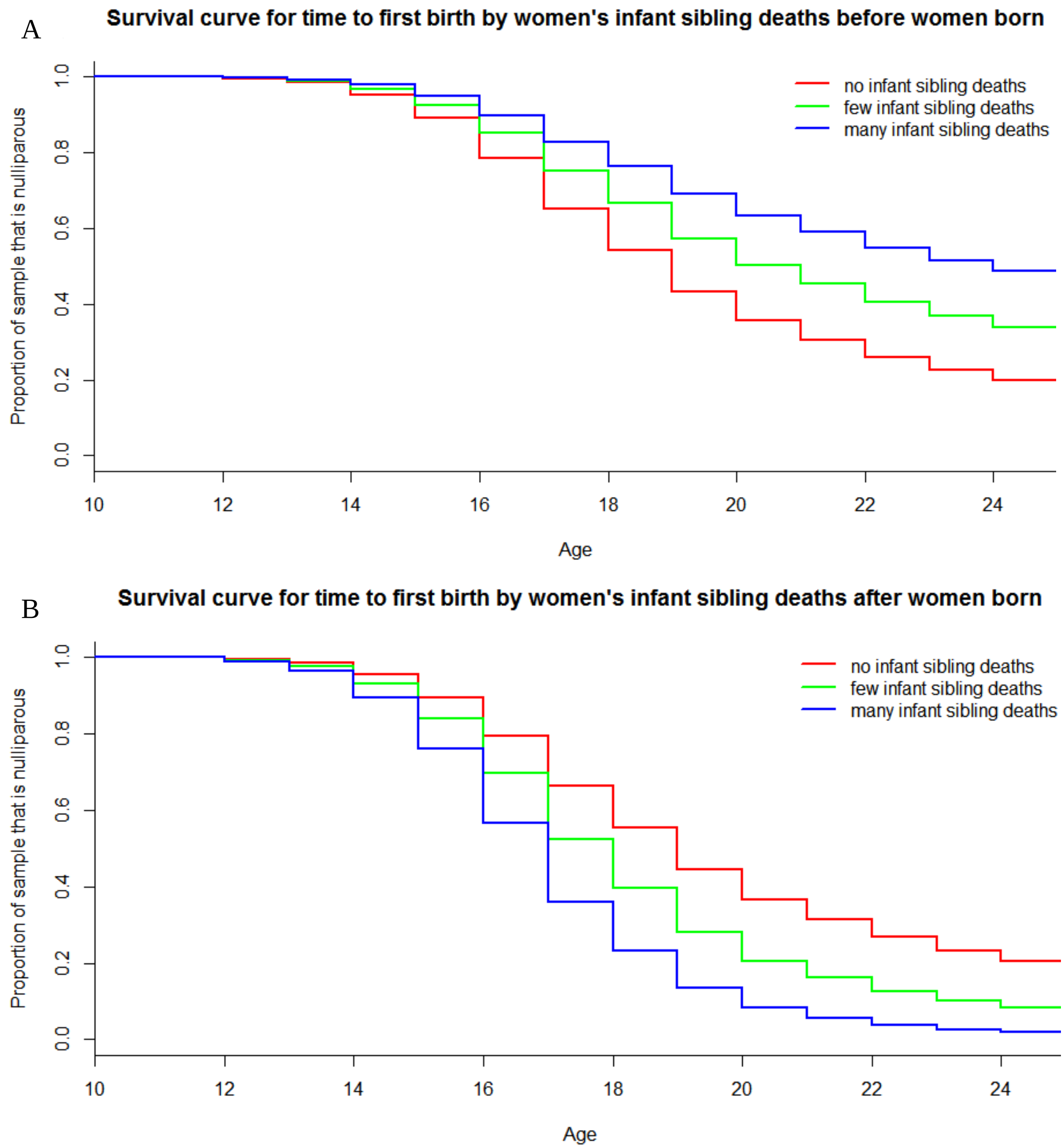


Figure 5. Women's progression to first birth as a functions of infant sibling deaths before ego's birth (A) and after ego's birth (B). Kaplan-Meier survival estimates from Cox proportional hazard models (Table 22 Model 2 and 3 respectively), with mean of covariates grouped by women's infant sibling deaths (no=0, few=3, many=6).

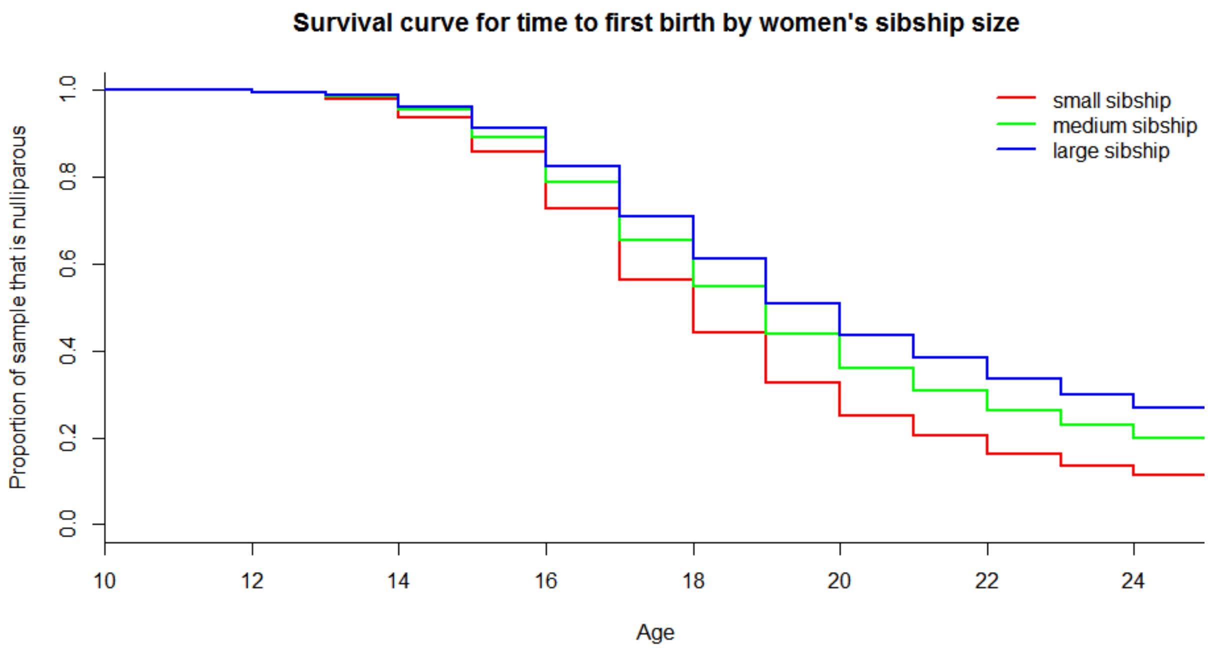


Figure 6. Women's progression to first birth as a function of her sibship size. Kaplan-Meier survival estimates from Cox proportional hazard models (Table 22) with mean of covariates grouped by women's sibship size (small = 3, medium = , large = 13).

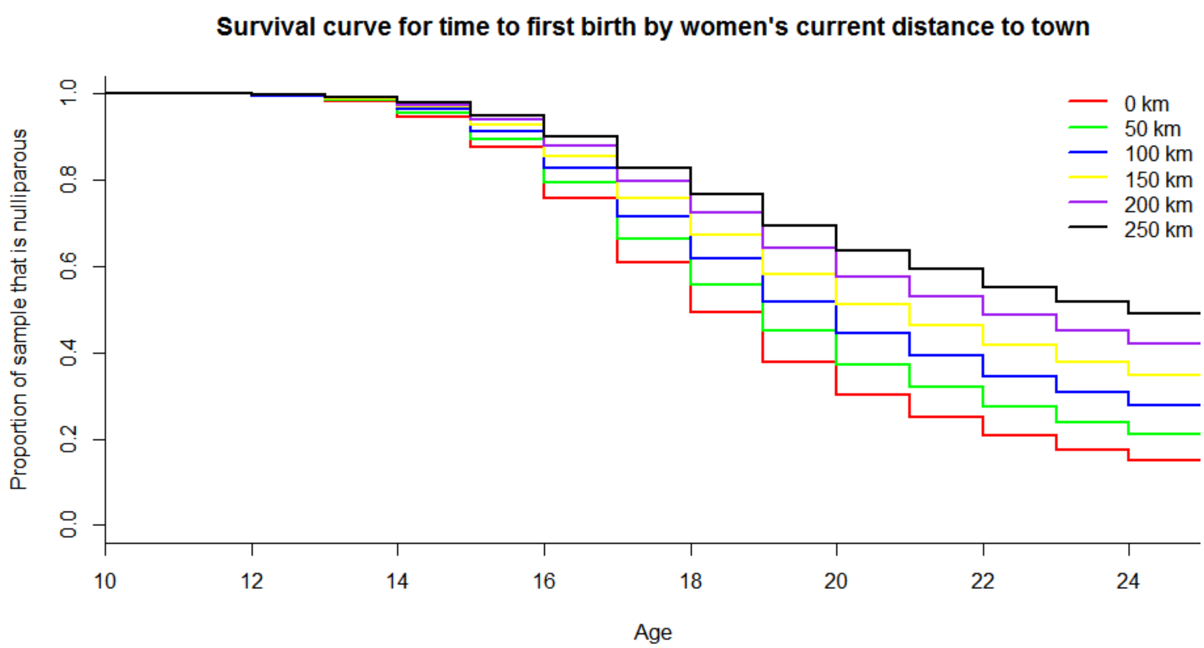


Figure 7. Women's progression to first birth as a function of the distance to town from their residential communities. Kaplan-Meier survival estimates from Cox proportional hazard models (Table 22), with the mean of covariates grouped by women's current distance to town in kilometers.

3.3. Experiences of sibling infant mortality and progression to second birth

The cumulative hazard of progression to second birth had a negative association with the total number of infant sibling deaths: Women who had more siblings die in infancy had longer intervals between their first and second births (Table 23 and Figure 8). The timing of infant sibling deaths, either before or after a woman was born showed no association with interbirth interval (see Appendix 1 Table 12). The interaction term, sibship size*sibling deaths, had a positive association with progression to second birth (Appendix 1 Figure 3). In larger sibships the effect of siblings' deaths in infancy on progression to second birth is muted: Women with large sibships who have many siblings die in infancy have shorter time to second birth rather than longer.

There is also a secular trend of longer progression to second birth over time (Figure 9): From 1980 to 1990 the median time to second birth increased by ~9.5 months. Women's age at first birth had a negative association with cumulative hazard of progression to second birth: Women who had their first birth at younger ages have shorter progressions to their second birth (Figure). For example, the median time to second birth for women who had their first child at 15 was ~2.5 months sooner than that of women who had their first child at 18, and ~5 months sooner than that of women who had their first child at 21.

Table 22. Women's progression to second birth as a function of proportion of siblings that died in infancy. Model is a Cox's regression (N = 711, Events = 540). Frailty term for family membership (N = 408) included in model to control for same family environment among sisters. Sibship size and sibship deaths are for siblings who were born or who died in infancy before the women's first birth.

Variable	All infant sibling deaths β (S.E.)
Distance to town (km)	0.001 (0.002)
Age	0.344 (0.061)***
Age2	-0.005 (0.001)***
Birth Order	0.002 (0.018)
Ego's age at first birth	-0.058 (0.018)***
Sibship size	0.004 (0.022)
Sibling deaths	-0.320 (0.145)*
Sibship size x sibling deaths	0.036 (0.014)*
Fraility term (mother's ID)	NS
AIC	10.404 6177.768
McFadden pseudo R2	0.017

† *p* <.10, * *p* <.05, ** *p* <.01, *** *p* <.001

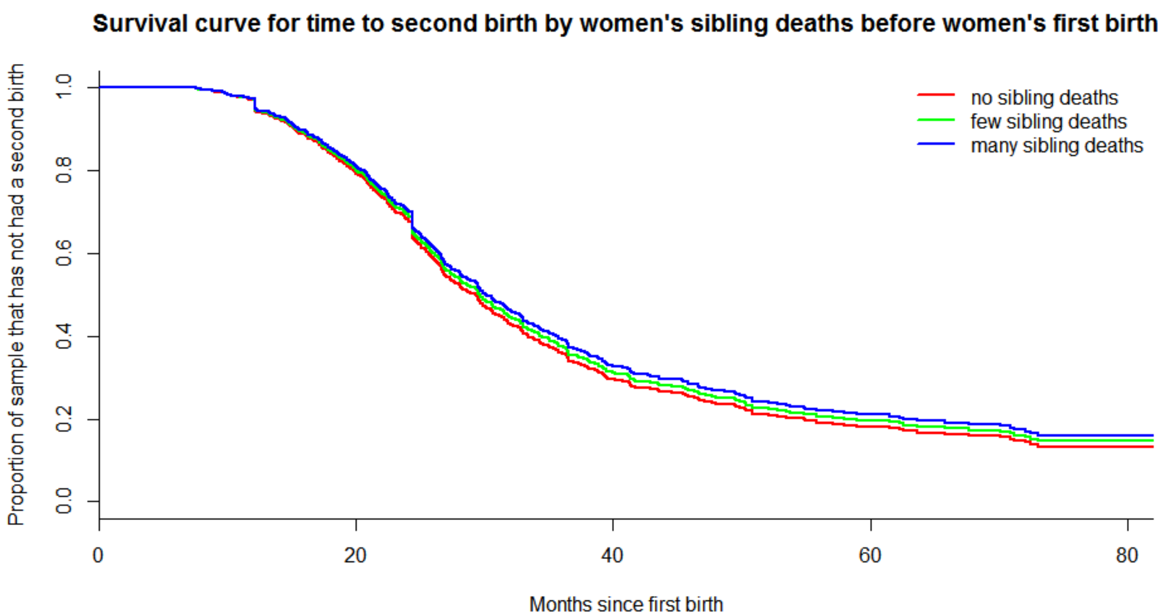


Figure 8. Women's progression to second birth as a function of sibling deaths in infancy. Kaplan-Meier survival estimates from Cox proportional hazard models (Table 23), with mean of covariates grouped by women's sibling deaths (no=0, few=3, many=6).

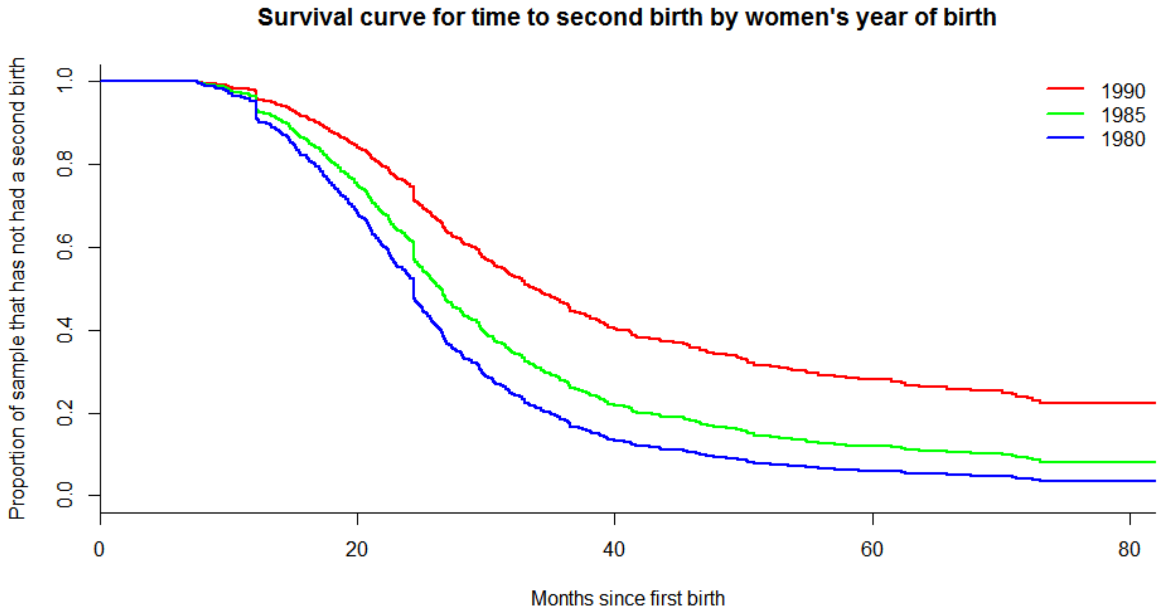


Figure 9. Women's progression to second birth as a function of year of birth. Kaplan-Meier survival estimates from Cox proportional hazard models (Table 23), with mean of covariates grouped by women's age in 2013 (shown her as year of birth, the ages were 23, 28, and 33).

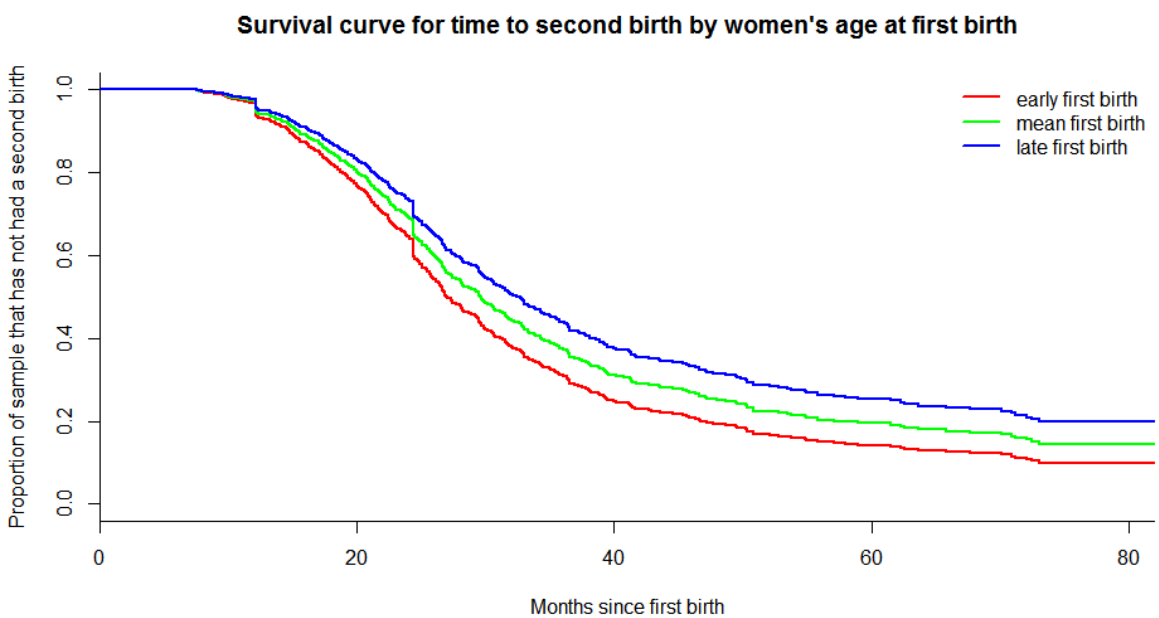


Figure 10. Progression to second birth as a function of women's age at first birth. Kaplan-Meier survival estimates from Cox proportional hazard models (Table 23), with mean of covariates grouped by women's age at first birth (early = 15, mean = 18 (~population mean), late = 21).

3.4. Experiences of sibling infant mortality and reproductive rate (parity-for-age)

Among parous Tsimane women, parity-for-age was unrelated to the total number of a woman's infant sibling deaths (Table 24, Model 1) or the number of infant sibling deaths after a woman was born (Tabe 24, Model 3). However, the number of infant sibling deaths that occurred before women were born trended toward a negative association with parity-for-age (Table 24– Model 2 and 4): Women with higher numbers of older siblings that died in infancy tend to have fewer children than the average for their age. The significant interaction terms in Models 2 and 4 indicate that the negative effect of older sibling deaths on parity-for-age is diminished by having a larger number of older siblings.

Unsurprisingly women who started their reproductive careers at younger ages have more children than the average for their age. We also found a positive association between women's parity-for-age and their mothers' parity-for-age suggesting heritable higher fecundity or larger kin networks supporting higher fertility. Model 1 also suggests that latter born children have larger parity-for-age.

Table 23. Women's parity-for-age as a function of proportion of siblings that died in infancy, and whether siblings died in infancy before or after a woman was born. Model are generalized linear mixed models (N=608). Random effect of family membership (N = 375) included in model to control for same family environment among sisters. Sibship size is for siblings born in the time period for which sibling deaths are counted. Moher's parity-for-age is with mother's age in 2013 if less than 45, otherwise it is cut at 45 years.

Variable	Model 1 β (S.E.)	Model 2 β (S.E.)	Model 3 β (S.E.)	Model 4 β (S.E.)
Intercept	4.927 (0.411)***	4.497 (0.327)***	4.823 (0.406)***	4.727 (0.380)***
Distance to town (km)	-0.002 (0.002)	-0.002 (0.002)	-0.002 (0.002)	-0.002 (0.002)
Birth Order	0.041 (0.021)†	-	-0.034 (0.032)	-
Mother's parity-for-age	0.197 (0.095)*	0.044 (0.046)	0.197 (0.096)*	0.160 (0.090)†
Woman's age at first birth	-0.232 (0.019)***	-0.241 (0.018)***	-0.231 (0.019)***	-0.232 (0.019) ***
All siblings born before woman's first birth				
Number of siblings	-0.088 (0.044)*	-	-	-
Number of dead siblings	-0.057 (0.150)	-	-	-
Siblings*sibling deaths	0.010 (0.015)	-	-	-
Before woman born				
Number of siblings	-	-0.001 (0.019)	-	-0.040 (0.032)
Number of dead siblings	-	-0.243 (0.143)†	-	-0.246 (0.146)†
Siblings*sibling deaths	-	0.044 (0.021)*	-	0.043 (0.021)*
After woman born				
Number of siblings	-	-	-0.077 (0.044) †	-0.061 (0.042)
Number of dead siblings	-	-	0.098 (0.137)	0.124 (0.138)
Siblings*sibling deaths	-	-	-0.008 (0.020)	-0.011 (0.020)
ACIC	1771.746	1765.196	1771.016	1776.377

† *p* <.10, * *p* <.05, ** *p* <.01, *** *p* <.001

4. Discussion

We predicted that exposure to high infant mortality rates in childhood encourages a faster life history pace, but that the timing of those deaths relative to a woman's birth (and hence direct exposure) may have different effects on her fertility-related behavior. We employ household level experience with sibling deaths as a first approximation of a woman's direct perception of environmental harshness. We find that exposure to infant sibling deaths is related to women's subsequent reproduction, but varies based on the timing of exposure. Exposure to older sibling deaths associated with indicators of a slower life history pace (i.e. delayed first births and lower parity-for-age); while, exposure to younger sibling deaths associated with a faster life history pace (i.e. earlier first births). We found infant sibling deaths, regardless of timing, were associated with a longer interval between first and second births. Siblings that die in infancy before a woman is born—unobserved sibling deaths--may change women's parent's behaviour, and this parenting behaviour may encourage slower life history strategies (e.g. women's parents invest more in children after an infant dies which may encourage children to have slower life history strategies). While, sibling deaths after women are born—observed sibling deaths—may indicate to women that they are in a high mortality risk environment and encourage faster life history strategies, including earlier age at first birth.

Overall, our findings suggest that the influence of sibling deaths on reproductive behaviour varies based on their timing, thus complicating simplistic predictions relating cues of higher exogenous mortality associating with a faster life history trajectory. However, sibling deaths may predominantly encourage a slower life history pace among the Tsimane.

In addition, women with larger sibships have later ages at first birth, and to some extent, lower parity-for-age, compared to women from smaller sibships. The lower parity-for-age may be a response to observing the difficulties their parents faced in raising a large family, and the hardships they faced as a child (e.g. greater diffusion of parental investment and resources). Among low birth order women with large sibships experiencing the burden of providing allocare to many younger siblings, while having few to no older siblings to provide allocare and help with resource acquisition may further encourage low parity.

Women closer to town have earlier ages at first birth, which may be related to their greater access to market goods and healthcare improving their nutrition and health, and thus enabling earlier reproduction. However, younger cohorts had older ages at first birth and slower progression to second birth. This may be a response to increased schooling opportunities and market integration in younger generations. However, given declines in mortality over time there is a general preference among the Tsimane for smaller family sizes now, with mother's preferring later ages at first birth and smaller family sizes for their daughters. The main reasons for preferring smaller family sizes being stated as concerns about food shortages, both agricultural and hunted. Women may have always preferred to have older ages at first birth and smaller family sizes, but only now be able to achieve these as familial and cultural support for lower fertility grows and the ability to support large families declines.

D. General Discussion

Life history theory and cross-cultural evidence suggest a negative association between extrinsic mortality risk and life history pace. Here we presented two studies that explore how women's experience and perceptions of mortality and morbidity are associated with their life history pace. Women's life history pace was assessed through their reproductive preferences for their children and selves, the timing of their first and second births, and their parity-for-age. Preferences may not be achieved due to lack of opportunity, or meeting the reproductive preferences of others, especially spouses. However, we assume that reproductive preferences are what women want given their underlying life history strategy.

The first study explored a possible pathway by which exposure to mortality may influence women's reproduction. We explored how women's experiences and perceptions of mortality, and perceptions of morbidity, influence their reproductive preferences for their children and themselves. Our results were mixed and we found evidence for divergent reproductive preferences for sons and daughters.

Women that had more of their children die in infancy, or perceived child mortality risk to be high in their community, favoured a slower life history pace for their daughters (older age at first birth, and smaller family size). However, women with many infant sibling deaths favoured large family sizes for their daughters, suggesting childhood experiences of infant mortality may lead to some fixation in life history pace.

Experiences of sibling and own children's infant deaths had no effect on women's reproductive preferences for their sons; but, high perceived morbidity and local child mortality risk associated with a preference for larger family sizes in sons – a fast life history pace. While, high perceived local child mortality risk associated with a preference for delayed age at first birth for sons – a slow life history pace. However, older ages at first birth for sons does not preclude large completed family sizes under high mortality and morbidity risk conditions; especially as women have shorter preferred interbirth intervals under perceived high morbidity risk conditions.

These difference in reproductive preferences for sons versus daughters, may relate to differences in reproductive potential between sons and daughters, and in the evaluation of sons versus daughters (and sons-in-law) abilities to support larger families. Also, women, due to greater shared experience, may also be more empathetic toward the hardships and risks of reproduction for daughters than for sons, and wish to protect their daughters from these.

A major issue with this study is the assumption that what women favour for their daughters correlates with what they would favour for themselves, and are thus indicators of their underlying life history strategy. Women favour different strategies for their sons and daughters, possible explanations for which were discussed previously. It is possible they favour different strategies for their daughters and themselves. Also, what women favour for their daughters is coloured by women's reproductive experiences, interactions with the preferences of others, cultural norms, perceptions of their daughters' conditions, and the current and future predicted environment. For example, women may consider their daughters to be higher or lower quality than themselves at that age, or they may predict different current and future environments for their daughters from what they experienced. Either of these would result in women perceiving their daughters to have different reproductive potentials from themselves, and thus women should favour different life history paces for their daughters than their own.

For our second study we explored whether high rates of infant mortality in childhood predicted a faster life history pace. We found that exposure to sibling infant deaths predicted the timing of women's first and second births, and their parity-for-age. However, whether the infant sibling deaths were associated with indicators of a fast or slow life history pace depended on their timing. Infant sibling deaths before a woman was born predicted an older age at first birth and lower parity-for-age – a slower life history pace. On the other hand, infant sibling deaths after a woman was born predicted a younger age at first birth -- a faster life history pace. Infant sibling deaths, regardless of timing, predicted longer time to second birth – a slow life history pace.

The disparate effects of infant sibling deaths based on their timing suggests different pathways through which mortality exposure may influence life history pace. The infant deaths of older siblings are not directly experienced. Women experience these deaths because they are told about them and/or through changes in their parents' parenting behaviour. We would expect being told about deaths to have a weaker, but comparable effect to directly experiencing the infant death of a younger sibling. For example, being told about an older sibling's death should encourage an earlier age at first birth just like experiencing the deaths of younger siblings appears to. However, older sibling infant deaths appear to have the opposite effect to younger sibling infant deaths on women's life history paces. One possibility is that changes in parents' behaviour encourage a slower life history pace when older siblings die in infancy. Although, infant deaths are not a taboo topic and are considered relatively commonplace, they are not common topics of discussion. Parents, surviving older siblings and extended family, are unlikely to have regularly discussed infant deaths with women during their childhoods.

As suggested by Störmer and Lummaa (2014), infant deaths may encourage parents to change their reproductive strategy, especially if they experience more than one infant death. Parents may invest more in each subsequent child to improve their survival chances, and subsequent children experience less competition for resources from older siblings. This may encourage a slower life history strategy for women who had many older siblings die. Interestingly, unlike here, Störmer and Lummaa (2014) found that all sibling deaths were more important than younger sibling deaths.

The infant deaths of younger siblings are more likely to be directly experienced and remembered. Women may have held the sibling, helped care for him/her and formed some attachment to him/her before s/he died. This may mean the sibling was grieved for. Pepper and Nettle (2013) found, among a sample of US adults, that high numbers of bereavements were associated with younger ages at first birth. Alternatively, direct observation of infant deaths may indicate a risky environment and encourage a faster life history pace independent of any emotional attachment to the younger sibling.

The mixed findings of our second study suggest the relationships between cues of mortality risk and life history pace are complex, and among the Tsimane infant sibling deaths may generally encourage a slower life history pace. This slower life history pace was unexpected but may be related to how high the Tsimane infant mortality rate is. Quinlan (2010) found, among a Caribbean community, that higher infant mortality rate was only associated with earlier ages at first and higher parity-for-age up to a point. Under conditions of extremely high infant mortality, more than 40 infant deaths per 1000 live births, the relationship reversed. The Tsimane infant mortality rate is much higher than this: Infant mortality rate across the Tsimane is 126 infant deaths per 1000 live births, though it ranges from ~80 to ~260 infant deaths per 1000 among villages (Gurven, 2012a). Quinlan (2010) suggested that this reversed relationship at higher rates of infant mortality is due to the environmental conditions that encourage high infant mortality rates also encouraging somatic depletion and energetic stress reducing women's fecundity.

We find some support for environmental conditions encouraging both higher infant mortality rates and low fecundity among the Tsimane. The leading cause of infant death among the Tsimane is infections (55% of infant deaths); and infant stunting (34% of infants), underweight (15% of infants) and wasting (12% of infants) are relatively common (Gurven, 2012a). Conversely, Tsimane women, despite engaging in heavy physical labor and having limited energy budgets, are not malnourished: A recent study found that only 1.2% of reproductive aged Tsimane women were underweight (BMI $\leq$ 18.5) (Gurven, Costa, et al., 2016). However, indicators of better condition in adolescence are associated with earlier transition to first birth (see chapter on teenage pregnancy and (Kaplan et al., 2015). Furthermore, Tsimane women's infectious load is high (e.g. 70% helminth prevalence), and may affect their fecundity (Blackwell et al., 2015): roundworm infection was associated with a faster life history pace (e.g. younger ages at first birth and shorter interbirth intervals), while hookworm infection was associated with a slower life history pace (e.g. older ages at first birth and longer interbirth intervals) (Blackwell et al., 2015).

E. Summary and future directions

In summation, simplistic predictions relating mortality to life history are not well supported. The relationship between mortality risk and life history pace is complex and timing specific, as are associated pathways by which cues of mortality risk are translated in to reproductive behaviours. More work is needed to explore how experienced mortality risk, and perceptions of mortality and morbidity risk influence life history. We propose five future directions to explore: (1) how siblings that died at older ages affect women's life history paces; (2) how infant mortality rates outside women's sibships and own reproduction influence their life history pace; (3) how cues and perceptions of mortality risk affect men's life history paces; (4) how different deaths -- whether a sibling, own child, others in the community -- affect individual time discounting; and (5) how people's perceptions of their ability to influence their own and their children's mortality affects the relationship between mortality risk and life history pace.

Our findings here, regarding no effect of perceived infant mortality rate versus the trends associated with perceived child mortality rate, suggest that siblings dying in childhood may have a stronger effect than siblings that died in infancy on women's life history paces. This may be due to a stronger attachment to siblings that survive infancy, i.e. siblings that are playmates and companions. This stronger attachment may cause greater bereavement upon the sibling's death and more strongly encourage a faster life history pace.

However, it should be remembered that, despite noticeable variation within the population, in general the Tsimane have a faster life history pace than most other populations. When high infant mortality is relatively ubiquitous and outside the control of the parents, it may lose value as a predictor of individual variation in life history pace. Instead, child mortality, which may be more associated with parents' ability to invest in children and thus resources access, may be a better indicator of environmental variation, and thus a more robust predictor of life history pace. Assessing whether an infant's or child's cause of death (both as diagnosed by a medical professional and perceived by the individual) affects the relationship between experiences of infant or child deaths and life history pace may address this.

Other work has looked at village level infant mortality rates to assess how infant mortality affects women's life history pace. Here we would like to explore whether sibship or village level infant deaths have the greater effect on women's life history pace. If the pathway by which exposure to infant mortality influences women's life history pace is based on bereavement, we would expect sibship infant mortality to have a greater effect than village level infant mortality. However, given the high relatedness within Tsimane villages this may be difficult to partition. We would also explore how the age of the woman when these deaths occurs affects her life history pace. There is evidence that although infant mortality rate in childhood influence a woman's age at first birth, it may be more affected by infant mortality in the year preceding her first birth (Quinlan, 2010).

The need to explore how men's life history paces are affect by experiences and perceptions of mortality risk is obvious. Reproduction is a two-body conundrum. The pace of a woman's life history cannot be understood without considering the life history pace of the man helping or hindering her in achieve the markers of her life history pace (e.g. age at first birth, interbirth intervals, lifetime fertility). This is especially important among a society like the Tsimane where women have low reproductive autonomy.

Fourth, we propose exploring how experiences of death influence time discounting. Time discounting is a viable indicator of life history pace and in broad terms an integral part of life history theory (Ellis et al., 2012; Griskevicius, Tybur, Delton, & Robertson, 2011; Hill, Ross, & Low, 1997.; Pepper & Nettle, 2013; Schechter & Francis, 2010). However, there has been a call for greater caution and clarity in conceptualizing how measures of "time preference" relate to more common measures of life history pace (e.g. pubertal timing, mating attitudes) (Copping, Campbell, & Muncer, 2014). Generally, individuals who discount the future more usually have faster life history paces than individuals who discount the future less: Individuals who discount the future more should prioritize reproduction. Unlike reproductive events, indicators of time discounting should be largely independent of the preferences of others and opportunity. Consequently time discounting may be a clearer indicator of an individuals' underlying life history pace. In conjunction with the timing of individuals' reproductive events, individuals' discount rates may further elucidate the effects of mortality risk on life history pace, and how much opportunity and the preferences of others limit individuals' abilities to achieve their underlying life history pace.

To date there has been some work with developed populations on the relationship between mortality risk and time discounting (Ellis et al., 2012a; Griskevicius, Tybur, et al., 2011; G. V. Pepper & Nettle, 2013). This work suggests that indicators of high mortality risk are associated with greater discounting of the future, and earlier ages at first birth. However, there is a need to explore these relationships in non-developed populations. Previous work on discount rates with the Tsimane have explored the effects of education, age, income, nutritional status, and drug use (Kirby et al., 2002), and suggest that basic time discounting methodology (small pot of money now or larger pot of money later) works well with this population. This work also showed that individual discount rates were somewhat consistent over time, although susceptible to situational factors. We suggest exploring whether Tsimane who have had greater exposure to death discount the future more. And, whether who died, their age at death, and the interviewee's age at death explain variation in time discounting. Given the longitudinal nature of the Tsimane Health and Life History Project, the consistency of individuals' time discounting rates and whether they are predictive of reproductive timing should also be explored.

Lastly, true examples of extrinsic mortality are rare. For example, death from a mortality shock, such as earth quake, wildfire, or flood can be avoided by not living in areas where such events are common. Although, knowing which areas to avoid may be in hindsight, individuals' may be limited in where they can live, or the benefits of living in that area may outweigh the potential costs (e.g. more fertile land of flood plains). And, deaths from infectious disease can be avoided, even within the most technological limited population, through basic hygiene practices, or in extreme cases relocating and leaving sick individuals behind -- deserting the sick was once a common Tsimane practice, which may help explain why they did not suffer any epidemics like other South American populations. Thus, extrinsic mortality risk contains elements of individual choice and opportunity. Assumedly, some of the choices individuals make that increase or decrease their extrinsic mortality risk are influenced by their perceived ability to control their morbidity and mortality.

Furthermore, with advancements in medicine, hygiene and technology, many extrinsic causes of death become preventable. These factors also affect individuals' locus of control for their morbidity and mortality. People's perceptions of their mortality risk, and their control over their morbidity and mortality vary, and this affects their willingness to invest in their health. In a North American sample, higher socioeconomic status was associated with lower perceived extrinsic mortality, which mediated higher investment in own health (G. V. Pepper & Nettle, 2014). While in Britain higher socioeconomic status was associated with weaker beliefs in the influence of chance on health and longer self-estimated life expectancy (Wardle & Steptoe, 2003). Among the Tsimane, wealthier and more educated Tsimane had greater faith in the abilities of medical professionals to help them when they were sick, but perceptions of own control over morbidity showed no significant variation (Alami Gouraftei, von Rueden, Blackwell, & Gurven, 2016). A better understanding of how individuals' locus of control for own and children's morbidity and mortality, and willingness to invest in own and children's health, mediate the relationship between mortality risk and life history pace may help explain our mixed findings.

III. The effects of education on women's ages of first birth and preferred ages of first birth for their children

This chapter is co-authored with Hillard Kaplan and Michael Gurven. Kaplan and Gurven as directors of the Tsimane Health and Life History Project provided logistical support in Bolivia. The author of this dissertation proposed all hypotheses tested herein and collected in Bolivia all data discussed. The analyses, writing, and figures contained in this chapter are the work of the author of this dissertation.

A. Introduction

On average, the higher a woman's level of educational attainment the older her age at first birth, the greater her use of contraceptives and the lower her fertility (John Bongaarts, 2003; John Bongaarts & Potter, 1983; Rosero-Bixby, Castro-Martín, & Martín-García, 2009; Snopkowski, Towner, Shenk, & Colleran, 2016; Westoff, 1992). These correlations are seen across and within populations (Basu, 2002; Caldwell, 1980; Lutz & Kc, 2011; T. C. Martin & Juarez, 1995; Snopkowski et al., 2016; Zurack, 1977). For example, in Bolivia women that graduated high school had fewer children than women with no education and those that had only completed primary school (Bailey, 1998; Snopkowski et al., 2016).

However, there are numerous examples across Africa, Asia and Latin America of education initiatives failing to delay age at first birth or reduce fertility, or fertility decline stalling (John Bongaarts, 2006, 2008; Howse, 2015; Shapiro & Gebreselassie, 2009). For example, education expansion initiatives in Malawi that provided free primary education and expanded secondary schooling since 1994, succeeded in increasing women's grade attainment, but failed to change women's age at first birth (Grant, 2015). Furthermore, teenage pregnancy and high unwanted fertility remain common in many small-scale societies, and rural areas of developing countries, despite increases in women's education, access to family planning programs, and strong stated preferences for fewer children by both men, women and their kin (Jejeebhoy, 1995; McAllister et al., 2012).

Our previous work with the Tsimane, lowland Bolivian forager-farmers, suggests that fertility decline in some populations may be hindered by the trifecta of low returns on investments in embodied capital linked to low socioeconomic mobility, perceived need for large kin networks, and continued preference for traditional somatic markers of success (McAllister et al., 2012). Here we explore how the relationship between Tsimane women's attained education, and preferred age of first birth and educational aspirations for their children may be mediated by their perceived returns on educational capital investments (prECI) in their children. Given the cost both financially and in loss of child labor to parents of supporting a child's education, children are unlikely to stay in school or delay first birth without familial support.

1. Theories of how women's education encourages fertility decline

For education to increase age of first birth it must delay individuals' sexual debuts, and/or limit their access to regular sex (i.e. by delaying age of marriage), and/or increase their use of contraceptives. Numerous theories for how education affects fertility have been proposed and have garnered mixed support. Here we focus on theories that directly address returns to investments in educational capital.

Investments in educational capital increase an individual's knowledge and skill set, which theoretically increases their access to and monetary value within the labor market (Becker, 1965, 2009; Willis, 1973). For women, significantly more so than men, time spent investing in education and joining the labor market directly conflicts with investing in reproduction, and there is a higher opportunity costs of bearing children in terms of potential lost income

(Becker, 1965). Consequently women have older ages of first birth, reducing their reproductive lifespan and lowering fertility.

Education may also increase women's economic independence and bargaining power within the household, including their ability to achieve their reproductive preferences (Abadian, 1996; Jejeebhoy, 1995). Also, assuming education allows women to earn money in "honourable" occupations, women's prestige within the family may become decoupled from their reproductive achievements, and shift to being accrued through education, knowledge and economic contribution (Akman, 2002; Jejeebhoy, 1995).

1.1. Does women's educational attainment influence their preferred age of first birth for their children?

If educational attainment shifts women's preferences for themselves it should shift their preferences for their children. This should be especially true where educational and labor market opportunities are, or are predicted to be, greater for children than they were for their parents. For example, more educated migrant women in Holland had older preferred ages at first birth for their children than less educated migrant women (De Valk & Liefbroer, 2007).

Parents' preferences for their children are predictive of their children's future behaviour. Inter-generational relationships between women's education, and educational aspirations for their children and educational achievement by their children have been observed in the Phillipines (Gipson & Hindin, 2015). Furthermore, several studies suggest that parents' fertility and family formation preferences are positively associated with their children's preferences (Acock & Bengtson, 1980; De Valk & Liefbroer, 2007; Glass, Bengtson, & Dunham, 1986; Thornton & Camburn, 1987); and that parental preferences directly influence children's preferences and behaviours (Axinn, Clarkberg, & Thornton, 1994; Axinn &

Thornton, 1993; Barber, 2001; De Valk & Liefbroer, 2007). Parent-to-child transmissions of preferences should be strongest for issues the parents find important. The timing of first birth has long-lasting effects on children's later life course, including educational attainment and labor market participation, and can affect both the child's and parent's material, socio-political and psychological well-being. Given this, parents should have a strong interest in influencing their children's timing of first birth (Barber, 2001; De Valk & Liefbroer, 2007; Geronimus & Korenman, 1992; Hoffman, 1998). We propose the following prediction, **Prediction 1. More educated women prefer older ages of first birth for children** (Figure 1: P1).

1.2. Why might education fail to delay age of first birth?

Several studies have suggested that the effects of education on age of first birth and fertility are highly dependent on local socioeconomic context: The relationship between education and fertility may be mediated by local kinship structure, level of socioeconomic development, socioeconomic mobility of individuals including accessibility of wage labor, community-levels of education, familial and behavioural genetic factors, and infant and child mortality decline (Barban, Mills, Mandemakers, & Snieder, 2014; Colleran, Jasienska, Nenko, Galbarczyk, & Mace, 2014; Jejeebhoy, 1995; Nisén, Martikainen, Kaprio, & Silventoinen, 2013; Snopkowski et al., 2016). In summary, returns to investments in educational capital, especially for women, may be limited by factors outside an individual's control. Of special concern is that an individual's access to the labor market, and/or value within it, may be limited by factors unrelated to their education – e.g. discrimination, gender inequality, women continuing to have low decision-making autonomy and/or low socioeconomic autonomy, low access to childcare support – or require greater educational investment than the individual has access to (Godoy et al., 2007; Grant, 2015; Perz, Warren, & Kennedy, 2008).

If educational investment does not have the expected payoffs then the negative relationship between education and fertility may not be observed, assuming lack of payoffs discourages prolonging investment in education. We propose that when women's access to the labor market is limited, and/or their value within the labor market is low, women will perceive low returns to educational capital investments. When prECI is low, there may be little motivation to delay reproduction to invest in education or reduce fertility. We propose, **Prediction 2. The effect of women's educational capital on their preferred age of first birth for their children will be mediated by their prECI: Women with higher prECI will prefer older ages of first birth for their children, than women with lower prECI** (Figure 1: P2).

1.3. Does the relationship between educational capital and age of first birth vary by offspring sex?

Educating men has been shown to have a weaker effect on fertility than educating women (Basu, 2002; Breierova & Duflo, 2004; Caldwell, 1980; Lutz & Kc, 2011). One possible reason is that men often have greater pre-existing mobility and access to wage labor in many developing countries where the effects of education on fertility preferences have been studied. For example, men have greater access to physical labor, greater pre-existing bargaining power within the household in patriarchal cultural contexts, and lower opportunity costs to childbearing. Education should increase prECI and preferred age of first birth for both sons and daughters. However, more educated women have greater experience of the limitations women face in utilizing their education. While less educated women retain the idealistic notions of education being beneficial for all espoused by teachers, government organizations and development agencies. **Prediction 3. Offspring sex moderates the relationships between women's educational capital, prECI and preferred age of first birth for their children: Women's educational capital has a weaker effect on prECI and preferred age of first birth for daughters than for sons** (Figure 1: P3).

1.4. Are greater educational aspirations associated with older preferred ages of first birth?

The premise that educational capital affects reproductive preferences has been shown across multiple populations (Bongaarts, 2003; Jejeebhoy, 1995; Martin & Juarez, 1995). Given that early reproduction limits educational attainment, especially in less developed populations where adult education and educational support for teenage mothers is limited, we expect a strong positive correlation between educational aspirations for children and preferred age of first birth for children. **Prediction 4: Women with greater educational aspirations for their children prefer older ages of first birth for their children than women with lower educational aspirations for their children** (Figure 1: P4).

Given that returns to educational capital investments are potentially limited by accessibility of wage labor and access to the market economy we control for women's perceptions of Tsimane men's and women's access to wage labor and their access to town (a proxy for the market economy) in our models. We also consider how familial wealth and interest in market goods may affect women's valuation of education and reproductive preferences. Here we use a composite of ownership of market goods and perceived importance of market goods as a proxy for familial wealth and interest in market goods.

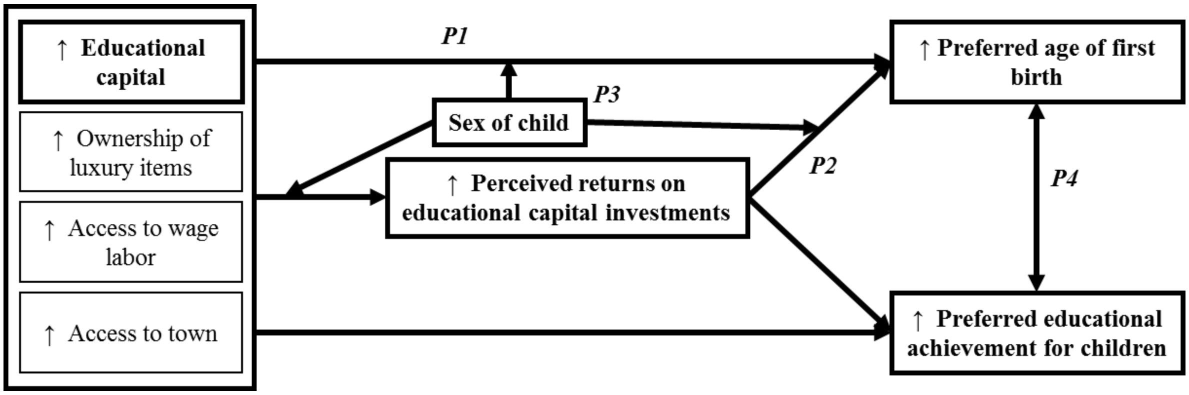


Figure 1. The pathways from women's educational capital to preferred age of first birth for children. Predictions 1 through 4 are shown as P1 to 4 respectively. prECI is shown as a mediator and sex of child as a moderator. Variables in bold are the focus of this paper, controls are not bolded.

The Tsimane are an ideal population in which to investigate how women's educational capital influences their preferred schooling and age at first birth for their children. Schooling is a relatively novel commodity for the Tsimane, but is becoming increasingly important for gaining access to the local market economy, as well as influence within the Tsimane (von Rueden, Gurven, & Kaplan, 2008). Accessibility of education, wage labor and the market economy varies among Tsimane villages. Women living closer to town generally have greater access to education and markets, and possess greater autonomy. However, there is variation and some women living in town are non-literate, unable to speak Spanish, rarely visit town and have few market goods in their homes; while, some women living far from town are literate, bilingual, own multiple luxury market goods and visit town as often as possible.

B. Methods

1. Study population

The Tsimane (pop. ~15,000) are semi-sedentary forager-horticulturists residing in the Bolivian Amazon. There are 90+ Tsimane villages ranging in size from 30 to 500 residents with residents grouped into extended family clusters, within which most food and labor sharing occurs. Over 90% of caloric intake is from farmed (plantains, rice, maize and yucca), foraged, fished, or hunted foods, with the remainder coming from market goods purchased in stores or traded for with traveling merchants (Martin et al., 2012).

The Tsimane are a rapidly growing population. Fertility is high at ~9.1 births per woman (McAllister et al., 2012), and the growth rate is high at 3.6% per year, despite a high infant mortality rate of 12.6% (Gurven, 2012; Gurven, Kaplan, & Supa, 2007). The Tsimane marry young and start reproducing shortly after marriage: Mean (±SD) age of marriage and of first birth for Tsimane women is 16.00 (±1.97) and 18.25 (±2.60) respectively. On average, husbands are 3.81 (±4.24) years older than wives.

1.1. Education

Bilingual schools were first introduced in several Tsimane villages in the 1970s through support of the New Tribes Mission, a United States-based evangelical Christian organization (Davis, 2014). The New Tribes Mission trained Tsimane (predominantly men) to provide basic primary education in reading, writing and arithmetic, and to act as pastors in their communities. However, classes were rarely stratified by age or ability, the value of education was poorly understood by many, the value of child-labor remained high, and the cultural practice of cloistering daughters in the home remained common. Consequently the effectiveness of these schools was minimal, especially for women.

Since the 1990s, with more aggressive support and funding after the election of Evo Morales in 2006, the number of Tsimane villages with schools has increased. However, only after 2000 did some of the larger villages gain middle or high schools, and stratification by age and ability become common. Prior to this, and continuing today, teenagers and adults in larger villages, who had completed primary school, could obtain a high school diploma by attending "adult education programs" offered for one week per month. Although breastfeeding mothers and women with dependents are encouraged to attend, childcare and household duties, and cultural norms regarding women not traveling alone, limit women's attendance at these adult education classes.

Today, Tsimane children attend school starting at age 5 or 6. Regardless of age or village, school lasts ~4 hours. The advantage is that this allows children to return home to assist their families and eat lunch. However, it severely limits the amount of instruction they receive, and as help with homework is often limited, progress through school can be slow with many Tsimane taking ~2 years to advance a grade.

The first years of primary school are taught in Tsimane language, but all later years solely in Spanish. Primary school teachers are thus often Tsimane men, and occasionally women; while, middle and high school teachers are normally non-Tsimane. Tsimane teachers are rarely placed in their home village, and non-Tsimane teachers are often far from family in a harsher environment than they are used to. Consequently, teachers rarely stay in a village over the weekend, but due to poor travel conditions are often unable to return by Monday, and retention of non-Tsimane teachers is low: School is often cancelled, and consistency of lesson material and follow up is poor.

Furthermore, teaching materials are often outdated and of low quality, availability of textbooks is low, and families struggle to afford school uniforms and school materials. Issues of low quality of education available to the Tsimane is exacerbated by relatively high truancy rates, both from children "hiding in the forest" to avoid school and parents keeping children with them to help with chores. School breaks are also long with little to no holiday follow through of taught materials. Thus, Tsimane children return to school needing many refresher weeks before new material can be taught.

"It is only a little important for a girl to have an education, as girls leave school at 16 and just get married and live with their husband. Girls should help more at home making chicha, getting wood and washing clothes. It is more important to learn to make good chicha and help in the home [than it is to attend school]."

45 year old mother of five from a village with only primary school

"Sons do not need a lot of education. It is more important they help their mothers and family. So when about 10 years old no more school. Instead sons can help their mothers at home and learn to fish, hunt and make chacos [agricultural fields]. These skills are more important. An adult male Tsimane does not need an education. More important to sell wood than read, write or Speak Spanish well."

27 year old mother of two from a village with a middle school.

"[It is] more important that a man knows how to make chacos, hunt and fish. He learns this from his father not from school."

17 year old mother of one from a village with a high school.

Attending school for girls is especially difficult. Firstly during menstruation regular attendance becomes difficult. There are no taboos forbidding girls from attending school during menstruation, but use of sanitary towels and tampons is extremely low in this population. Instead women use rags that they regularly wash. However, the efficacy and comfort of these rags is low and many girls avoid attending school during menstruation. Secondly, Tsimane culture to some degree cloisters girls within the home; and, there is a general sense that allowing girls out from the watchful eye of family results in earlier initiation of sex and pregnancy outside of marriage. Mothers seem especially concerned about the negative gossip surrounding teenage daughters that attend school, and that their daughters attend school to look for sex.

> *"Girls looking for boys and having sex outside of marriage has always been a problem. Before the girls would sneak off. Now they just find boys at school and no one knows. Some parents like their daughters to look for husbands at school. However, the number of young unmarried mothers is much higher now. It is too high now."*

47 year old mother of eleven from a large village with a high school.

> *"When girls go to school they get many girlfriends and together they look for boys. Last year this was a big problem and now there are very few girls at the school as they are all married now. Married to men different from the boys they were with. The boys they were with were too young to be husbands."*

35 year old mother of seven from a large village with a high school

> *"People say it is better girls do not go to school, because girls get pregnant at school."*

41 year old mother of seven from a small village with only a primary school.

However, in general, and especially among younger parents, education is becoming increasingly valued and many Tsimane want both their sons and daughters to graduate high school.

> *"[I want my daughter to] know how to read, write and speak Spanish. Unlike me who cannot do these things as I never went to school. If a woman can speak Spanish, and read, and write then she can sell things to napos [non-Tsimane]. If a woman cannot not speak Spanish, or read, or write, then the napos will [swindle] her."*

20 year old mother of two from a village with only a primary school

> *"It is very important that girls learn to read and write correctly. Then they can search for jobs and they can earn money in the shade and not in the sun."*

22 year old mother of two from a village with only a primary school

> *"It is very important that sons attend school, so that they can talk to napos well. So they can defend their land and not sell away their land accidently or have it stolen by napos."*

29 year old mother of three from a village with a high school

However, despite some expression of the value of education for obtaining employment and leading a less traditional life, obstacles may limit the potential motivation for Tsimane to attain higher levels of schooling. Opportunities for wage labor for Tsimane are limited, short-term, male-biased, and most do not require formal schooling. Additional schooling did not predict greater wage earnings in a sample of 257 Tsimane households across 13 villages, and even moderate Spanish fluency bore no association with wages (Godoy et al., 2007). Furthermore, the Tsimane, like many rural indigenous populations (Perez et al., 2008), face discrimination, further limiting viable employment opportunities. Consequently, socioeconomic mobility is low for the Tsimane, with many Tsimane women feeling a life in town (a non-traditional life) is infeasible (McAllister et al., 2012).

A number of Tsimane see being a teacher as a viable option for their children, and stress the importance of their children being educated so that they can become teachers.

> *"If a man, or a woman, has a bachiller [high school diploma] and can read and write well, and speak Spanish well. Then he [or she] can be a teacher and help the children in his [or her] village to learn. And he [or she] can defend the village from napos and perhaps be the village chief one day."*

42 year old mother of six from a village with a high school

However, teaching positions are limited and increasingly filled by non-Tsimane. Also, being away from family is especially difficult for female Tsimane teachers: Women must be accompanied by a male relative to the village with the school, and if there is no family in that village they will have no help with childcare. A few women have found teaching positions in their home villages. However, despite greater access to allocare, childcare duties still constrain their ability to teach. Although it is easier for Tsimane men to move between villages, the wages are rarely considered sufficient and most male Tsimane teachers try to maintain agricultural fields either in their home village and/or in their work village. The politics of gaining access to agricultural land, the time commitment farming requires, and the need to protect crops from thieves, as well as hunt and fish to supplement the diet, constrain men's ability to commit to teaching regularly.

1.2. Data collection

From July-September 2010 and April-August 2011, 176 Tsimane women, aged 13 to 85, from seven Tsimane communities were interviewed one to three times in private. The main project consisted of three surveys that could be taken in one sitting or at different times. The data presented here are from the first (N = 176) and third survey (N = 124). Information on residential proximity to town, fertility-at-interview and age-at-interview was collected during reproductive histories and other interviews collected by the Tsimane Health and Life History Project, and updated by LSM in 2010 and 2011.

The seven study villages (Chapter II: Table 2) vary in distance to town, accessibility of healthcare, quality of school (whether only primary available, or up to middle or high school, the degree of stratification by age and ability, qualifications of teachers), morbidity and mortality (Gurven, 2012a; Gurven et al., 2007; Kaplan et al., 2015), and fertility rate (Kaplan et al., 2015; McAllister et al., 2012). The characteristics of each village, relevant to this paper, are summarized in Chapter II: Table 1

All homes within a one hour walking distance of the village center were visited, and all women residents 13 years or older were invited to participate. For women that expressed an interest in participating, a date, time and location for the interview were agreed upon. Approximately 41% of women from these seven communities were interviewed. Among villages, percent of women interviewed varied from 25% in the largest village (pop. > 600) to 100% in smaller villages (pop. ≤ 125). Difference in coverage are due to many houses in larger villages being outside the one hour travel radius from the village center, and some women being less available due to traveling further from home to labor in their agricultural fields. Also, in two villages ~50% of the women left one week after the community meeting for a group fishing expedition that lasted several weeks. Women who were not interviewed, however, do not differ systematically with respect to age, parity, and other variables of interest (Appendix 1 Table 2). Chapter II: Table 1 shows the fertility and mortality statistics for this subsample.

To assess women's educational capital and level of market integration women were asked a series of questions split across surveys 1 and 3. Appendix 2 Table 1 summarizes the questions asked. Women's responses to questions about educational capital were compared, where possible, to educational data gathered by the Tsimane Health and Life History Project from 2002 to 2014 to confirm their reliability.

Perceived returns on educational capital investments in children were assessed on the third survey by asking women how important it is for sons and daughters to attend school, be bilingual or literate. Women were then asked to free-list the positive and negative outcomes of being educated. To assess reproductive preferences for children, women were asked about their preferred ages of marriage and first birth for both sons and daughters; and prompted for reasons to support their stated preferences. Women's educational aspirations for children were assessed by asking women the highest school grade they wanted their sons and daughters to obtain and whether they wanted their sons and daughters to get high school degrees (*bachiller*). Appendix 2 Table 1 and 3 describe the independent and dependent variables used in our models and how these were coded. Appendix 2 Table 2, 4 and 5 show the correlation matrices among the independent and dependent variables. Operationalization of variables is discussed below.

1.3. Sample characteristics

A smaller sub-sample of 92 women is used here as these women had no missing data (32 women that completed all three surveys were excluded). Women with missing data do not systematically vary in respect to age, parity, and other variables of interest. The mean ±SD age of sampled women was 33.5 ±15.0 years, 15.8% were nulliparous, and 60% of women had at least one child aged 6 to 15 attending school at time of interview. Among the parous women (n=73), 10.0% had only daughters, and 8.8% only sons. Among all women sampled, 74.7% had ever attended school and the mean ±SD years of schooling was 4.1 ±3.9. In addition, 55.8% of women had at least some ability to read and write in Spanish, and 50.6% could speak at least some Spanish.

Among the parous women, attending school, regardless of final grade achieved, and being literate or bilingual had no association with age of first birth once controlling for women's age and distance from town (Pearson's r controlling for age = -.130, p = .243; Table 1). It is not surprising that age and distance to town have strong effects given that many remote villages only acquired schools within the 5 years previous to the date of interview, and the quality of schools increases closer to town.

Table 1. Correlation matrix for parous women (N = 73), showing correlations among women's education variables, and ages of first birth and parity-for-age. Pearson bivariate correlation shown above the diagonal, and a partial correlation controlling for age and distance to town shown below the diagonal.

	Age	Distance to town	Attended school	Spanish literacy	Spoken Spanish fluency	Years of schooling	AFR	Parity-for-age
Age	-	.175	-.329***	-.380***	-.283*	-.404***	.486***	.457***
Distance to town	-	-	-.148	-.116	-.171	-.023	.276*	.088
Attended school	-	-	-	.572***	.401***	.641***	-.057	.091
Spanish literacy	-	-	.487***	-	.653***	.695***	-.244*	-.104
Spoken Spanish fluency	-	-	.332**	.614***	-	.531***	-.225*	-.139
Years of schooling	-	-	.597***	.644***	.487***	-	-.269**	-.110
AFR	-	-	.151	-.063	-.079	-.105	-	.439***
Parity-for-age	-	-	.289*	.085	-.011	.091	.285*	-

* = p < 0.05, ** = p < 0.01, *** = p < 0.001

2. Variable operationalization

2.1. Educational capital and market integration

Women's educational capital and level of market integration were assessed from thirteen questions (Appendix 2 Table 1 describes these measures, and Table 2 shows the correlations among the measures). A principal components analysis (PCA) was run on nine of the questions. Questions assessing access to wage labor for Tsimane men and women were not included in the PCA as they are binary coded. The suitability of PCA was assessed prior to analysis. Inspection of the correlation matrix showed all variables had at least one correlation coefficient greater than 0.3 (Appendix 2 Table 2). The overall Kaiser-Meyer-Olkin (KMO) measure was 0.62 (KMO measures > .60 indicate a PCA would be useful), with individual KMO measures between .51 and .80, classifications of 'miserable' to 'meritorious' according to Kaiser (1974) (KMO > .50 is considered the minimum advisable). Bartlett's Test of Sphericity was statistically significant ($p < .0005$), indicating that the data were likely factorizable.

PCA revealed three components with eigenvalues greater than one and which explained 33.8%, 22.4%, and 15.9% of the total variance, respectively. Visual inspection of the scree plot indicated that all components should be retained (Cattell, 1966) (Appendix 2 Figure 1). In addition, a three-component solution met the interpretability criterion.

The three-component solution explained 72.2% of the total variance. A Varimax orthogonal rotation was employed to aid interpretability. The rotated solution exhibited 'simple structure' (Thurstone, 1947). The interpretation of the data was consistent with the market integration attributes the questions were designed to measure with strong loadings of women's *educational capital* on Component 1, *access to town* on Component 2, and *ownership of luxury items* on Component 3 (Table 2**Table**).

Table 2. Rotated structure matrix for PCA with Varimax rotation of eight questions assessing women's level of market integration.

	Rotated component coefficients			
Items	**1**	**2**	**3**	**Communalities**
Educational Capital				
Spanish literacy	**.905**	.080	.068	.763
Years of schooling	**.873**	.020	-.003	.829
Spoken Spanish fluency	**.844**	.160	.059	.741
Access to town				
How often visits town	.083	**.818**	.066	.691
Proximity to town	.060	**.809**	.180	.681
Visits town without a male relative	.098	**.789**	.111	.644
Ownership of luxury items				
Number of luxury items owned	.079	.119	**.916**	.860
Number of types of luxury items owned	-.032	.017	**.911**	.831
Importance of owning luxury items	.085	.332	**.576**	.449

Note. Major loadings for each item are bolded.

Access to wage labor was assessed separately for Tsimane women and men, as the sum of whether wage labor is both available and can reliably provide income to women and men, respectively.

2.2. Perceived returns on educational capital investment (prECI)

Women's prECI for sons and daughters were assessed through five questions (Appendix 2 Table 3 describes these measures, and Appendix 2 Table 4 shows the correlations among the measures and the principle components shown in Table 2). PCA was employed for data reduction purposes for sons and daughters separately. The data for both sexes was suitable for a PCA: All variables had at least one correlation coefficient greater than 0.3 (Appendix 2 Table 4); and the KMO measure was 0.80 for sons and 0.81 for daughters, with individual KMO measures between .77 and .89, classifications of 'middling' to 'meritorious' according to Kaiser (1974). Bartlett's Test of Sphericity was statistically significant ($p < .0005$) for both sexes, indicating that the data were likely factorizable.

PCA for both sons and daughters revealed one component with an eigenvalue greater than one and which explained 65.25% of the total variance for sons, and 66.13% of the total variance for daughters. The interpretation of the data for both sexes was consistent with the prECI attributes the questions were designed to measure (Table 3).

Table 3. Non-rotated structure matrix for PCA of five questions assessing women's prECI for sons and daughters. Rotated matrix not possible as there was only one component with an eigenvalue greater than one for both sexes.

	Component coefficients			
	Sons		**Daughters**	
Items	**Component 1**	**Communalities**	**Component 1**	**Communalities**
Perceived number of negative outcomes of being educated (reverse coded)	0.832	0.692	0.896	0.803
Perceived number of positive outcomes of being educated	0.704	0.496	0.82	0.673
Importance of attending school	0.847	0.717	0.763	0.582
Importance of being bilingual	0.774	0.598	0.811	0.658
Importance of being literate	0.709	0.503	0.768	0.59

3. Data analysis

We used structural equation modelling (SEM) in IBM SPSS Amos (v. 24), using the maximum likelihood method, to analyse path models predicting women's preferred age of first birth and educational aspirations for their children. We used SEM to estimate a series of regression models to obtain direct, indirect, and total effects of our independent variables on women's preferred age of first birth and educational aspirations for their children. SEM also allowed us to assess whether prECI is a mediating variable and the strengths of all variables (coefficients were standardized). We compare preferences for sons and daughters separately, except when exploring whether child sex is a moderator.

We compared a model without prECI to a model with prECI to assess whether prECI explained additional variance in the outcome variables. We then eliminated all pathways from the full models with prECI that indicated poor fit to produce the constrained models. Model fit was also assessed. Values above 0·90 for Goodness-of-Fit Index (GFI), Adjusted

Goodness-of-Fit Index (AGFI), and Comparative Fit Index (CFI) were considered a good fit. Root mean square error of approximation (RMSEA) less than 0·06 was considered an adequate fit, though may be overestimated given our small sample size. Additional Akaike information criteria (AIC) were considered – lower values indicate better fit. To compare models we also examined the χ^2 differences and the amount of variance (R^2) explained by each model. To test the robustness of the indirect and direct effects suggested by SEM we used bootstrapping (20,000 samples) and examined the standardized direct and indirect effects matrices.

Our final sample size is small for SEM (N = 92). Running the models with a larger sample size (N = 176), and imputing data for missing variables, produced the same patterns as described here (results not shown). Furthermore, there is a growing body of literature suggesting that the 10 subjects per model parameter with a minimum of 100 to 200 subjects rule-of-thumb is out-dated (Sideridis, Simos, Papanicolaou, & Fletcher, 2014; Wolf, Harrington, Clark, & Miller, 2013): Sample size requirements are case specific and a minimum sample size of 70 may be allowable here.

To assess whether child sex moderates the relationship between *educational capital* and preferred age at first birth for children or educational aspirations for children, we compared models with an interaction term between *educational capital* and child sex to models without the interaction term. A moderator analysis of a dichotomous moderator (i.e. child sex) is usually explored through hierarchical multiple regression and comparing R^2 values. However, for this analysis women appear twice in the data (once for daughters and then again for sons), which is controlled for via random effects in generalized linear mixed methods. This makes hierarchical multiple regression and the comparison of R^2 values no longer an option.

Consequently we focus on corrected Akaike information criterion as an indicator of model fit, and the directionality and significance of regression pathways in the models.

C. Results

1. The effects of women's educational capital on their reproductive preferences for their children

Women's preferred ages at marriage and first birth were approximately three years older for sons than for daughters (Table 4). Mean preferred age of first birth for daughters (19.92 ±2.45) was approximately 2.5 years older than the interviewees' mean age of first birth (17.51 ±2.44: $t(82) = -6.618$, $p < 0.001$). Preferred time from marriage to first birth did not vary by child sex.

Table 4. Women's reproductive preferences for their children. Whether stated preferences for sons and daughters are correlated is assessed by Pearson's *r* controlling for women's age, parity, and educational capital. Whether women's preferences for sons versus daughters differ is shown by paired *t*-tests and χ^2.In parentheses are the degrees of freedom for the *t*-test and χ^2.

	Mean ±SD			
Variable	**Daughter**	**Son**	***R***	**Comparison by sex**[a]
Preferred for children				
Age at first marriage	18.46 ±2.34	21.14 ±3.16	0.50***	$t(91) = -8.97$***
Age at first birth	19.92 ±2.45	22.63 ±3.51	0.55***	$t(91) = -8.61$***
Time marriage to first birth	1.47 ±0.87	1.49 ±1.05	0.33**	$t(91) = -0.17$

* = p < 0.05, *** = p < 0.001

Correlations among independent variables and preferred age of first birth for children are shown in Table 5. Women's age and educational capital were negatively correlated: Younger women tend to have more educational capital than older women. However, adding age or parity-for-age to the models did not change the relationships among the variables of interest (results not shown). Positive correlations were found between women's prECI for daughters and sons, and preferred ages of first birth for daughters and sons.

Table 5. Correlation matrix of the model components with the Pearson's *r* shown. Above the diagonal are the bi-variate correlations among all variables. Below the diagonal are the partial correlations with women's age controlled for. Age, parity-for-age and women's age at first birth are not included in the models discussed here as they did not significantly affect the model outcomes.

	Age	Parity-for-age	Age at first birth (N = 83)	PC Educational capital	PC Access to town	PC Ownership of luxury items	Access to wage labor for men	Access to wage labor for women	PC prECI for daughters	PC prECI for sons	Preferred age at marriage for daughters	Preferred age at first birth for daughters	Preferred time from marriage to first birth for daughters	Preferred age at marriage for sons	Preferred age at first birth for sons	Preferred time from marriage to first birth for sons
Age	-	.454***	.436***	-.464***	-.047	.136	-.132	-.138	-.082	-.064	-.075	-.042	.086	.032	.055	.085
Parity-for-age	-	-	.457**	-.192	.000	-.023	.016	-.021	.056	.041	.003	.043	.112	-.005	.011	.050
Age at first birth (N = 83)	-	.322***	-	-.285**	-.302**	.016	.087	-.039	-.143	-.070	.068	.081	.041	.120	.183	.226*
PC Educational capital	-	.024	-.130	-	-.022	-.040	.123	.191	.201	.064	.029	.033	.013	-.143	-.173	-.151
PC Access to town	-	.023	-.304**	-.049	-	.091	-.007	-.169	.274**	.294**	.025	.032	.021	.202	.160	-.073
PC Ownership of luxury items	-	-.096	-.047	.027	.099	-	.075	-.023	.011	.088	.021	-.009	-.083	.239*	.207*	-.028
Access to wage labor for men	-	.086	.145	.071	-.014	.094	-	.105	-.105	-.037	.220*	.244*	.089	.110	.072	-.088
Access to wage labor for women	-	.047	.032	.144	-.178	-.005	.089	-	-.042	-.016	.175	.207*	.109	.043	.021	-.058
PC prECI for daughters	-	.105	-.117	.184	.272**	.023	-.117	-.054	-	.580***	.196	.190	.005	.233*	.201	-.030
PC prECI for sons	-	.078	-.042	.038	.291**	.097	-.046	-.025	.578***	-	.086	.068	-.043	.193	.177	.012
Preferred age at marriage for daughters	-	.042	.115	-.006	.022	.032	.213*	.166	.191	.082	-	.935***	-.078	.491***	.514***	.241*
Preferred age at first birth for daughters	-	.069	.119	.015	.030	-.004	.240*	.203*	.188	.066	.936***	-	.280**	.492***	.538***	.317**
Preferred time from marriage to first birth for daughters	-	.082	.022	.060	.025	-.097	.102	.122	.012	-.037	-.072	.285**	-	.056	.122	.239*
Preferred age at marriage for sons	-	-.022	.141	-.144	.204*	.237*	.115	.048	.237*	.196	.495***	.494***	.053	-	.956***	.187
Preferred age at first birth for sons	-	-.016	.201	-.168	.163	.202*	.081	.029	.206*	.181	.520***	.541***	.118	.956***	-	.468***
Preferred time from marriage to first birth for sons	-	.013	.223*	-.127	-.069	-.040	-.078	-.047	-.024	.017	.249*	.322**	.234*	.185	.466***	-

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

1.1. More educated women do not prefer older ages at first birth for their children than less educated women.

Prediction 1 was not supported. Women's *educational capital* had no direct effect on preferred age of first birth for daughters (Table 6 Model 1a; Appendix 2 Figure 2a); and trended toward a negative association with preferred age of first birth for sons (Table 7 Model 2a, Appendix 2 Figure 3a). Women with more *educational capital* may have younger preferred ages of first birth for their sons than women with less *educational capital*.

Among our control variables we found that preferred age of first birth for daughters was positively predicted by *access to wage labor for women* (Table 6 Model 1a; Appendix 2 Figure 2a). While *ownership of luxury items* trended toward a positive association with preferred age of first birth for sons (Tabe 7 Model 2a, Appendix 2 Figure 3a).

1.2. prECI mediates the relationship between women's educational capital and preferred age of first birth for daughters, but not for sons.

Prediction 2 was not supported: prECI does not mediate the relationship between women's *educational capital* and their preferred age of first birth for daughters (Table 6 Model 1b; Appendix 2 Figure 2b), or sons (Table 7 Model 2b, Appendix 2 Figure 3b). For daughters mediation was not possible as women's educational capital did not predict their preferred age of first birth for daughters. However, *prECI for daughters*, which is positively predicted by women's *educational capital*, is positively associated with preferred age of first birth for daughters (Table 6 Model 1b). The indirect effect of *educational capital* on preferred age of birth for daughters was significant (Table 7 Model 1b). More educated women perceive higher returns to investments in daughters' education than less educated women; and women that perceive the returns to investments in daughters' education to be higher prefer older ages at first birth for daughters compared to women who perceive the returns to be lower.

For sons, we found women's *educational capital* had no association with prECI. However, as with daughters, *prECI for sons* positively predicted preferred age of first birth for sons.

Additionally, we found, for both daughters and sons, that prECI is positively predicted by *access to town* (Daughters: Table 6 Model 1b; Appendix 2 Figure 2b; Sons: Table 7 Model 2b, Appendix 2 Figure 3b). This indirect effect was significant for both daughters and sons (Table 8 Model 1b and 2b respectively). Women with greater *access to town* reveal higher *prECI for their daughters* than women who perceive town to be inaccessible (Table 6 Model 1b; Appendix 2 Figure 2b). Women with higher *prECI for their daughters* preferred older ages of first birth for their daughters. A similar, trend was found for sons, but only in the constrained model (Table 7 Model 2c, Appendix 2 Figure 3c).

Overall, prECI is an important factor predicting women's preferred ages of first birth for their children. With prECI present the model explained 9% of the variance in preferred age of first birth for daughters and 11% for sons, compared to ~5% and 9% respectively without prECI (Table 9: Daughters: no prECI = 1a, with prECI = 1b-c, Sons: no prECI = 2a, with prECI = 2b-c).

Also, for both daughters and sons, the constrained models had the best fit (Table 9: Daughters: Model 1c; Sons: Model 2c; Figure 2a and b respectively). Comparing within child sex, the $\chi 2$ differences between the constrained models (Model 1c and 2c respectively) and the full models (Model 1b and 2b respectively) were insignificant suggesting the constrained model fits statistically well (Table 9). For daughters, the constrained model (1c) and full model (1b) explained approximately 12% of the variance in *prECI for daughters*, and approximately 9% of the variance in preferred age of first birth for daughters (Table 9). For sons, the constrained model (2c) explained 1.1% less of the variance in *prECI for sons* at 8.6%, and 1.4% less of the variance in preferred age of first birth for sons at 9.6%, than the full model (Tabe 9 Model 2b (full) and 2c (constrained)). Consequently we strongly suggest Model 1c as the best fit and most parsimonious model for predicting preferred age of first birth for daughters (Table 6 Model 1c; Figure 2a), and cautiously suggest Model 2c for predicting preferred age of first birth for sons (Table 7 Model 2c, Figure 2b).

Table 6. Women's *educational capital* has no association with preferred age of first birth for daughters, and prECI is not a mediator between *educational capital* and preferred age of first birth. However, prECI is positively predicted by *educational capital* and *access to town*, and prECI positively predicts preferred age of first birth. *Access to wage labor* for women has a direct effect on preferred age of first birth for daughters. Estimated coefficients (b), standard error of these coefficients (SE), critical ration, standardized estimated coefficient (β) and p-value (p) are shown. Error terms for each model are also shown (e1 and e2). For visualizations of these models see Appendix 2 Figure 2. Standardized coefficients significant at $p < 0.10$ are in bold.

	Model 1a (no prECI)					**Model 1b (full model with prECI)**					**Model 1c (constrained model with prECI)**				
Relationship	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**
Regression path to prECI for daughters															
Educational capital	-	-	-	-	-	0.221	0.102	2.168	**0.213**	0.03	0.214	0.102	2.100	**0.206**	0.036
Access to town	-	-	-	-	-	0.295	0.106	2.779	**0.273**	0.005	0.301	0.106	2.833	**0.279**	0.005
Ownership of luxury items	-	-	-	-	-	-0.008	0.124	-0.063	-0.006	0.95	-	-	-	-	-
Access to wage labor for women	-	-	-	-	-	-0.043	0.115	-0.372	-0.037	0.71	-	-	-	-	-
Error term						0.902	0.134	6.745	-	< 0.001	0.903	0.134	6.745	-	< 0.001
Regression path to preferred age of marriage for daughters															
Educational capital	-0.02	0.255	-0.078	-0.008	0.938	-0.13	0.257	-0.507	-0.052	0.612	-	-	-	-	-
Access to town	0.181	0.266	0.683	0.070	0.495	0.034	0.271	0.127	0.013	0.899	-	-	-	-	-
Ownership of luxury items	-0.034	0.310	-0.108	-0.011	0.914	-0.03	0.304	-0.097	-0.01	0.922	-	-	-	-	-
Access to wage labor for women	0.618	0.287	2.149	**0.219**	0.032	0.639	0.282	2.267	**0.227**	0.023	0.605	0.282	2.143	**0.215**	0.032
prECI for daughters	-	-	-	-	-	0.498	0.257	1.936	**0.206**	0.053	0.480	0.242	1.988	**0.199**	0.047
Error term	5.658	0.839	6.745		< 0.001	5.434	0.806	6.745	-	< 0.001	5.405	0.808	6.745	-	< 0.001

Table 7. Women's *educational capital* and *ownership of luxury items* are directly associated with preferred age of first birth for sons. Women's *educational capital* and *prECI for sons* are not associated. However, *access to town* is positively associated with *prECI for sons*, and prECI positively predicts preferred age of first birth for sons. Estimated coefficients (b), standard error of these coefficients (SE), critical ration, p-value (p), and standardized estimated coefficient (β) are shown. Error terms for each model are also shown (e1 and e2). For visualizations of these models see Appendix 2 Figure 3. Standardized coefficients significant at $p < 0.10$ are in bold.

	Model 2a (no prECI)					Model 2b (full model with prECI)					Model 2c (constrained model with prECI)				
Relationship	**B**	**±SE**	**Critical ratio**	**β**	**P**	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**
Regression path to prECI for sons															
Educational capital	-	-	-	-	-	0.077	0.097	0.791	0.079	0.429	-	-	-	-	-
Access to town	-	-	-	-	-	0.293	0.101	2.898	**0.289**	0.004	0.298	0.102	2.929	**0.294**	0.003
Ownership of luxury items	-	-	-	-	-	0.081	0.118	0.684	0.068	0.494	-	-	-	-	-
Access to wage labor for men	-	-	-	-	-	-0.130	0.258	-0.504	-0.050	0.614	-	-	-	-	-
Error term						0.819	0.121	6.745	-	< 0.001	0.832	0.121	6.856	-	< 0.001
Regression path to preferred age of marriage for sons															
Educational capital	-0.620	0.357	-1.738	**-0.174**	0.082	-0.662	0.354	-1.871	**-0.186**	0.061	-0.634	0.356	-1.781	**-0.178**	0.075
Access to town	0.521	0.371	1.405	0.140	0.160	0.361	0.383	0.942	0.097	0.346	-	-	-	-	-
Ownership of luxury items	0.789	0.434	1.82	**0.182**	0.069	0.745	0.43	1.733	**0.172**	0.083	0.805	0.433	1.860	**0.185**	0.063
Access to wage labor for men	0.773	0.947	0.816	0.082	0.415	0.844	0.938	0.900	0.089	0.368	-	-	-	-	-
prECI for sons	-	-	-	-	-	0.546	0.381	1.435	0.149	0.151	0.632	0.365	1.732	**0.173**	0.083
Error term	11.040	1.637	6.745	-	< 0.001	10.796	1.601	6.745	-	< 0.001	12.273	1.790	6.856	-	< 0.001

Table 8. *prECI* is not a mediator between women's *educational capital* and preferred age of first birth for children. However, there is a significant indirect effect of *educational capital* on preferred age of first birth for daughters through *prECI for daughters*; and of *access to town* on preferred age of first birth for both sexes via prECI. Bootstrapping (20,0000) was used in IBM SPSS AMOS (v.24) to assess whether prECI is a mediator. Standardized direct and indirect effects shown.

Mod.	Hypothesis	Direct	Indirect	Result
Daughters				
1b	Educational capital → prECI → preferred age of first birth	-0.052	0.044*	Indirect effect
	Access to town → prECI → preferred age of first birth	0.013	0.056*	Indirect effect
	Ownership of luxury items → prECI → preferred age of first birth	-0.010	-0.001	No relationship
	Access to wage labor → prECI → preferred age of first birth	0.227*	-0.008	No mediation
	prECI → preferred age of first birth	0.206*	NA	Direct relationship
1c	Educational capital → prECI → preferred age of first birth	0.000	0.041*	Indirect effect
	Access to town → prECI → preferred age of first birth	0.000	0.056*	Indirect effect
	Access to wage labor → preferred age of first birth	0.215*	0.000	Direct relationship
	prECI → preferred age of first birth	0.199*	0.000	Direct relationship
Sons				
2b	Educational capital → prECI → preferred age of first birth	-0.186	0.012	No relationship
	Access to town → prECI → preferred age of first birth	0.097	0.043*	Indirect effect
	Ownership of luxury items → prECI → preferred age of first birth	0.172	0.010	No mediation
	Access to wage labor → prECI → preferred age of first birth	0.089	-0.007	No relationship
	prECI → preferred age of first birth	0.149†	NA	Direct relationship
2c	Educational capital → prECI → preferred age of first birth	-0.178	NA	Direct relationship
	Access to town → prECI → preferred age of first birth	0.000	0.051**	Indirect effect
	Ownership of luxury items → preferred age of first birth	0.185	NA	Direct relationship
	prECI → preferred age of first birth	0.173*	NA	Direct relationship

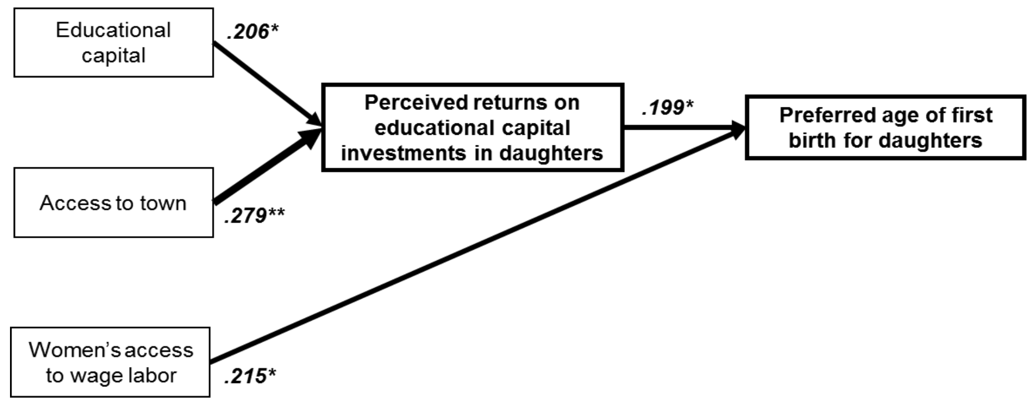
† = $p < 0.10$, * = $p < 0.05$, ** = $p < 0.01$

Table 9 Goodness-of-fit statistics and model comparisons for the full and constrained models for women's preferred ages of marriage for their children.

Model[a]	Goodness-of-fit index criteria[b]								Model comparisons					R²	
	$\chi2$	*df*	*p*	RMR	GFI	AGFI	CFI	RMSEA	$\chi2$ diff.	*df*	*p*	AIC	CAIC	prECI	Preferred age of first birth
Daughters															
1a	6.924	6	0.328	0.069	0.970	0.926	0.318	0.041	-	-	-	24.924	56.620	-	0.053
1b	6.924	6	0.328	0.058	0.975	0.914	0.920	0.041	-	-	-	36.924	89.751	0.121	0.091
1c	6.423	6	0.378	0.059	0.973	0.932	0.973	0.028	0.501	0	> 0.05	24.423	56.119	0.120	0.086
Sons															
2a	2.936	6	0.817	0.041	0.998	0.969	1.000	< 0.001	-	-	-	20.936	52.632	-	0.090
2b	2.936	6	0.817	0.035	0.990	0.964	1.000	< 0.001	-	-	-	32.936	85.763	0.097	0.110
2c	2.710	6	0.844	0.100	0.988	0.971	1.000	< 0.001	0.226	0	> 0.05	20.710	52.406	0.086	0.096

a. Models 1a and 2a: Basic model with no prECI. Models 1b and 2b: Theoretical models with prECI as a mediator. Model 1c: Modified model for daughters with ownership of luxury items removed from the model, and regression paths from educational capital and access to town to preferred age of first birth removed, and access to wage labor to prECI removed. Model 2c: Modified model for sons with access to wage labor for men removed from the model, and regression paths from ownership of luxury items and educational capital to prECI , and from access to town to preferred age of first birth removed.
b. Values above 0·90 for Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), and Comparative Fit Index (CFI) are considered a good fit. Root mean square error of approximation (RMSEA) <0·06 indicate an adequate fit, but for a small sample RMSEA is usually overestimated

(a) Predictors of preferred age of first birth for daughters



(b) Predictors of preferred age of first birth for sons

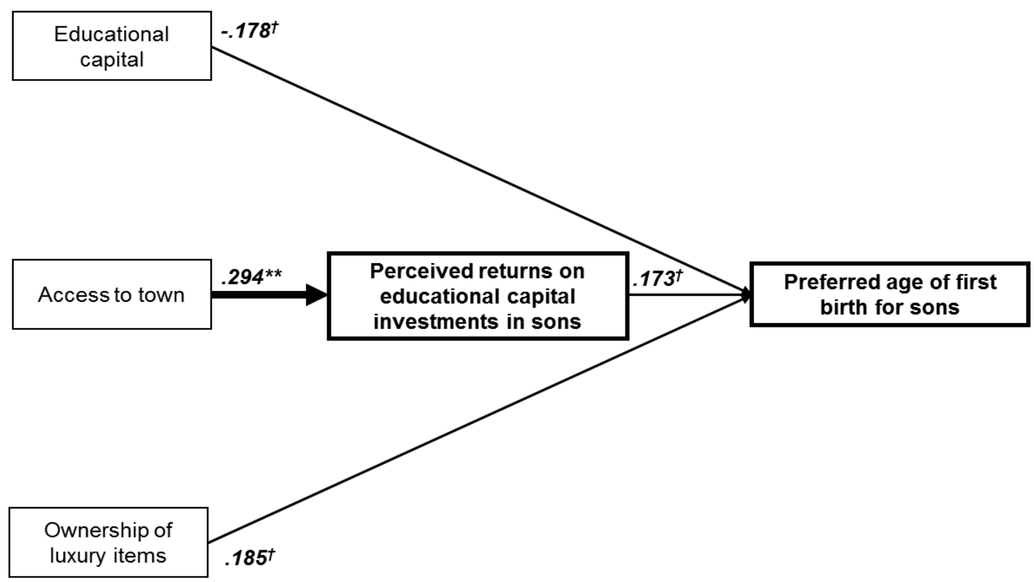


Figure 2. Path analysis of the pathways between women's educational capital and their preferred age of first birth for their children. The constrained models are shown: (a) daughters and (b) sons. Standardized coefficients are shown. † = $p < 0.10$, * = $p < 0.05$ and ** = $p < 0.01$.

1.3. The effect of women's educational capital on their preferred age of first birth for a child is moderated by the sex of the child.

Prediction 3 is partially supported. The coefficient of the interaction term between *educational capital* and child sex (0.586 ±0.323) trended toward being significant (p = 0.071): Women's *educational capital* may have less of a reducing effect on preferred age of first birth for daughters than for son (Table 10 Model 3b; Figure 3a). Child sex does not moderate the relationship between women's *educational capital* and prECI (β= 0.150 ±0.124, p = 0.124); nor between prECI and preferred age of first birth (Table 10 Model 3f).

Additionally, child sex moderates the relationship between *ownership of luxury items* and preferred age at first birth for children (Table 10 Model 3d; Figure 3b): Owning more luxury items increases preferred age of first birth for sons relative to daughters. Child sex did not moderate the relationship (Table 10 Model 3c and 3e respectively).

Table 10. Child sex moderates the relationship between educational capital and preferred age of first birth for children. Standardised coefficients from general linear mixed models, with women's ID as a random effect, are shown. Corrected Akaike information criterion (AIC_C), shown here, suggest that Model 3b and 3d better fit the data than the no-interaction term model (Model 3a).

	Model 3a			Model 3b			Model 3c			Model 3d			Model 3e			Model 3f		
Variable	β	±SD	p	β	±SD	p	β	±SD	p	β	±SD	p	β	±SD	p	β	±SD	p
Intercept	22.416	±0.325	<0.001	22.443	±0.325	<0.001	22.435	±0.325	<0.001	22.431	±0.323	<0.001	22.605	±0.403	0.001	22.408	±0.326	<0.001
Educational capital	-0.373	±0.275	0.177	-0.651	±0.316	0.041	-0.367	±0.276	0.185	-0.364	±0.276	0.188	-0.367	±0.277	0.187	-0.362	±0.277	0.192
Access to town	0.209	±0.293	0.476	0.219	±0.293	0.456	0.424	±0.337	0.210	0.216	±0.293	0.461	0.214	±0.295	0.468	0.206	±0.294	0.485
Ownership of luxury items	0.367	±0.331	0.270	0.370	±0.332	0.267	0.368	±0.332	0.269	**0.800**	±0.384	0.039	0.377	±0.334	0.261	0.360	±0.333	0.281
Access to wage labor	**0.540**	±0.296	0.070	0.472	±0.295	0.112	0.486	±0.298	0.105	**0.501**	±0.292	0.087	-0.005	±0.740	0.995	**0.534**	±0.296	0.073
prECI	**0.456**	±0.238	0.057	0.404	±0.238	0.091	**0.454**	±0.238	0.058	**0.421**	±0.236	0.076	**0.456**	±0.238	0.057	**0.629**	±0.303	0.039
Child sex (0 = male, 1 = female)	**-2.277**	±0.378	<0.001	-2.331	±0.374	<0.001	**-2.315**	±0.378	<0.001	**-2.308**	±0.371	<0.001	**-2.438**	±0.426	<0.001	**-2.280**	±0.377	<0.001
Interaction terms																		
Educational capital * child sex		-	-	**0.586**	±0.323	0.071	-	-	-	-	-	-	-	-	-			
Access to town * child sex		-	-	-	-	-	-0.437	±0.338	0.198	-	-	-	-	-	-			
Ownership of luxury items * child sex		-	-	-	-	-	-	-	-	**-0.862**	±0.385	0.026	-	-	-			
Access to wage labor * child sex		-	-	-	-	-	-	-	-	-	-	-	0.628	±0.787	0.426			
prECI * child sex																-0.322	±0.346	0.353
AIC_C	899.298			**896.468**			897.965			**894.454**			897.314			898.722		

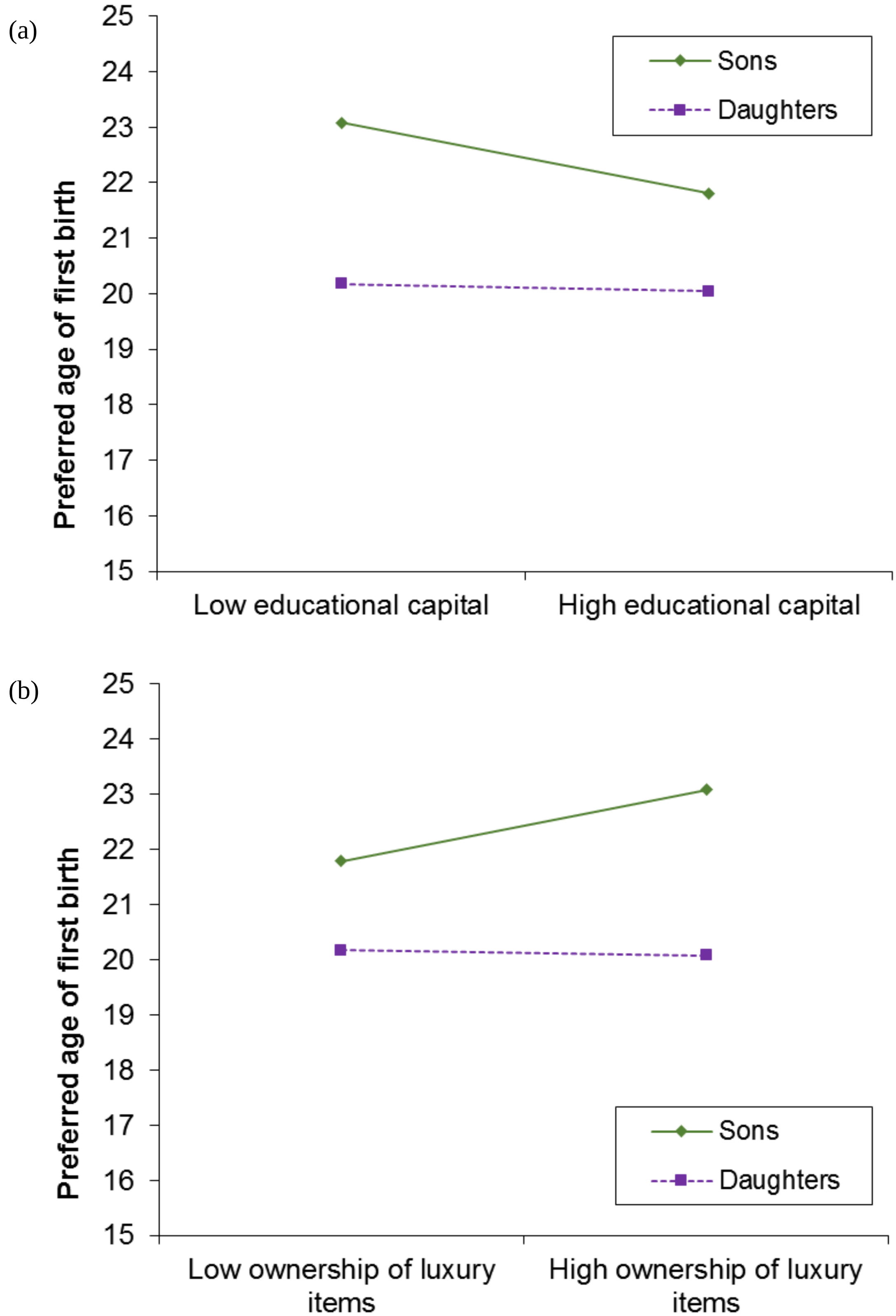


Figure 3. Plot of the effect of the interaction between child sex and (a) *educational capital* and (b) *ownership of luxury items* on preferred age of first birth for children.

2. Educational aspirations for children

Women want their children to be more educated and achieve a higher school grade than they did. Among women that attended school and for whom their final school grade was known (N = 66), mean final school grade was 3.03 ±2.55, compared to 6.00 ±2.63 for daughters and 6.35 ±2.73 for sons.

However, women may have greater educational aspirations for sons than for daughters (Table 11): Women trend toward having higher desired school grade for sons and are more likely to want a son to get a bachiller than a daughter.

Table 11. Women's educational aspirations for their children. Pearson's *r* controlling for women's age, parity, and educational capital, and paired *t*-tests and χ^2 for sons versus daughters for each variable are shown. In parentheses are the degrees of freedom for the *t*-test and χ^2.

	Mean ±SD			
Variable	**Daughter**	**Son**	***r***	**Comparison by sex**
School grade want for children	5.60 ±2.98	6.03 ±3.03	0.659***	$t(91) = -1.81^{\dagger}$
Want children to get a *bachiller* (0 = no, 1 = yes)	0.46 ±0..50	0.54 ±0.50	0.649***	$\chi^2(1) = 40.66$***

** = p < 0.01, *** = p < 0.001

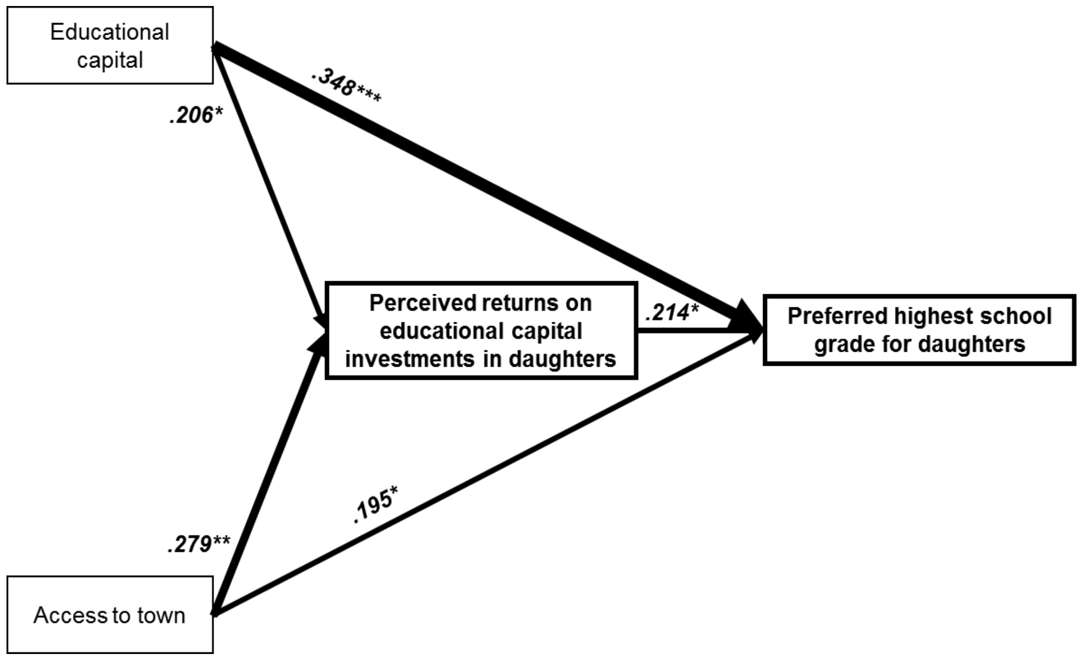
2.1. Women with greater educational aspirations for their children do not prefer older ages at first birth for their children.

For both daughters and sons, highest school grade desired is positively associated with women's *educational capital*, *access to town*, and prECI (Figure shows the constrained models, see Appendix 2 Table 6 and 7, and Appendix 2 Figures 5 and 6 for all models tested for daughters and sons respectively). Furthermore, the relationships between *educational capital*, and *access to town*, and highest school grade desired for daughters was partially mediated by *prECI for daughters* (Figure , Appendix 2 Tables 8 shows the indirect and direct model effects supporting *prECI* as a mediator, and Appendix 2 Table 6 Model 1b-c show all mediation models). For sons, the relationship between *educational capital* and preferred age of first birth was not mediated by *prECI for sons*; however, the relationship between *access to town* and preferred age at first birth was partially mediated by *prECI for sons.* Having prECI in the models explained ~4% and ~8% more of the variance for daughters and sons, respectively, in highest school grade desired (Appendix 2 Table 9).

Despite these relationships between educational capital, prECI and educational aspirations, there is no association between women's educational aspirations for their children and their preferred age at first birth for their children: Pearson's correlation between highest school grade desired for child and preferred age of first birth, controlling for women's age and *educational capital*, daughters r = -.01 (p = .92); sons r = .146 (p = .17). Correlations are shown in Appendix 2 Table 5.

We also used general linear mixed models, with an interaction term between *educational capital* and child sex, to explore whether women's *educational capital* is associated with differing levels of schooling desired for sons versus daughters. Despite possibly having greater educational aspirations for sons than for daughters (Table 11) we found no evidence that child sex is a moderator between *educational capital* and highest school grade desired for children (Appendix 2 Table 10 Model 3b, Figure 5, interaction term: β = -0.072 ±0.251, p = 0.774) and the model had a higher Akaike information criterion than the no interaction model (Appendix 2 Table 10 Model 3a), suggesting poorer fit to the data.

(a) Predictors of highest school grade desired for daughters



(b) Predictors of highest school grade desired for sons

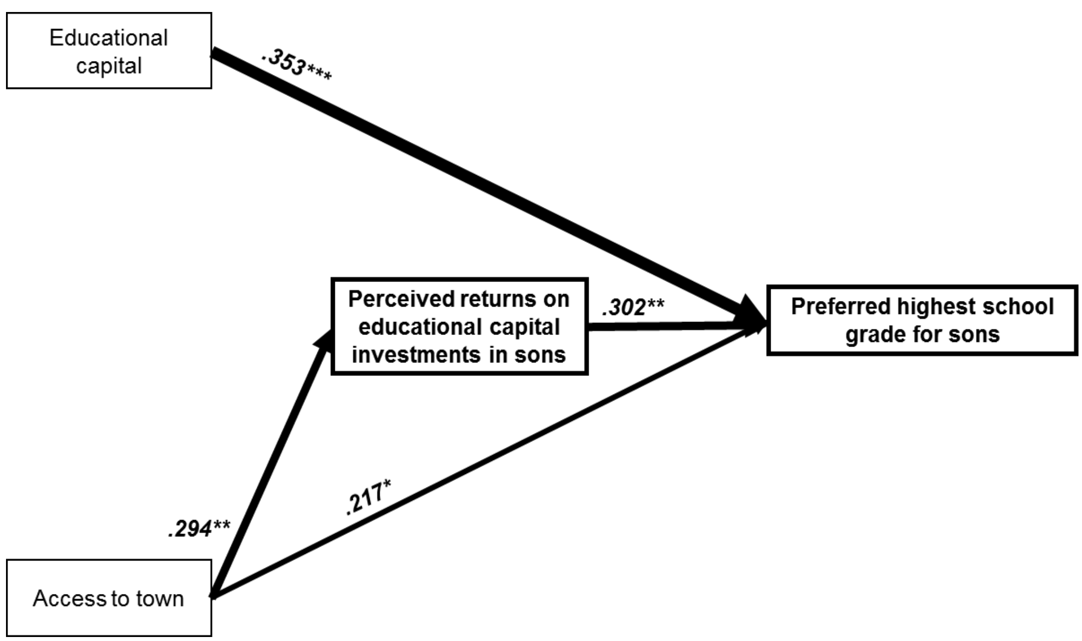


Figure 4. Path analysis of the pathways between women's *educational capital* and their highest school grade desired for children. The constrained models are shown. (a) daughters and (b) sons. Standardized coefficients are shown. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

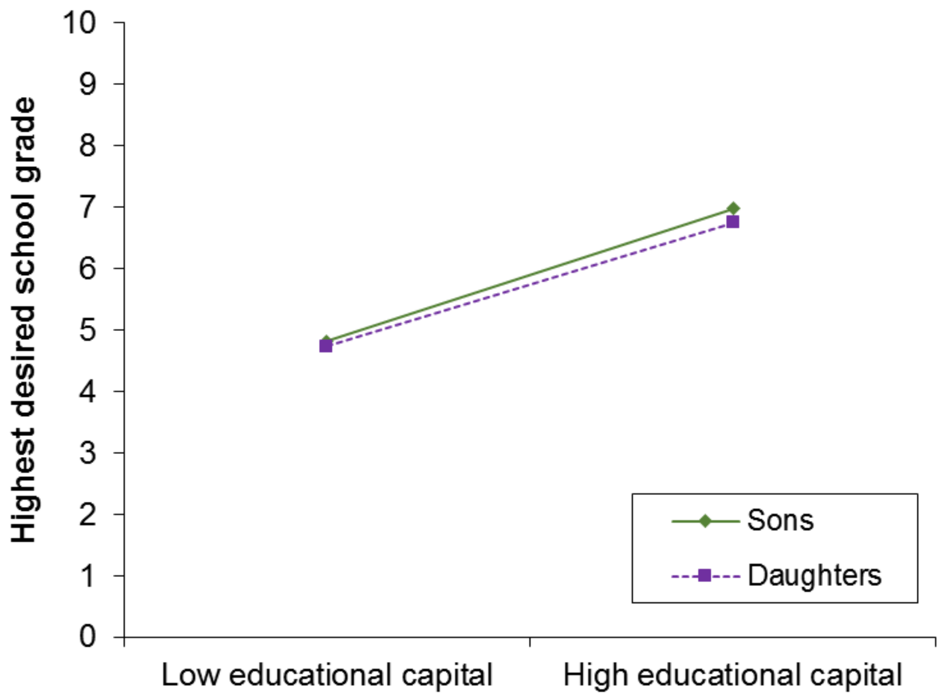


Figure 5. Plot of the effect of the interaction between child sex and *educational capital* on highest desired school grade for children.

We were concerned some Tsimane women may be confused by the school grade system given that in many villages students of multiple ages work in a single classroom and high school is only available in a few villages. Consequently, women were also asked if they wanted their children to get a bachiller (equivalent to a high school diploma). Logistic regression analyzing predictors of whether women want their children to get a bachiller supports a disconnect between educational aspirations for children and preferred age at first birth for children. Women's preferred age at first birth for their children, regardless of child sex, had no association with whether they wanted their children to get a bachiller or not (Table 12). However, wanting a child to get a bachiller was positively predicted by women's *educational capital* and *access to town*. More educated women and women with greater access to town – school quality and availability of education through high school or beyond is more available closer to town – were more likely to want their sons and daughters to get bachillers than less educated women and women for whom town is less accessible.

Table 12. Whether women wanted their children to obtain a bachiller (0 = no, 1 = yes) was not associated with preferred age of first birth. However, as with highest school grade desired for children, women's *educational capital*, *access to town*, and prECI positively predicted wanting a child to obtain a bachiller. Variable in models were chosen as they positively predicted highest school grade desired for children. However, models with more variables were also tested (data not shown). Additional variables were non-significant and did not change the relationships shown here. Odds ratios (O.R.) with $p < 0.05$ are in bold.

							95% Wald CI for O.R.	
Parameters	B	SE	Wald χ^2	*df*	*p*	O.R.	Lower	Upper
Daughters								
Intercept	-1.961	2.277	0.742	1	.389	0.141	0.002	12.199
Educational capital	0.573	0.263	4.735	1	.030	**1.774**	1.059	2.972
Access to town	0.697	0.287	5.888	1	.015	**2.007**	1.143	3.524
prECI	0.779	0.291	7.183	1	.007	**2.178**	1.233	3.850
Preferred age of first birth	0.093	0.114	0.662	1	.416	1.097	0.877	1.372
Sons								
Intercept	-1.655	1.948	0.722	1	.396	0.191	0.004	8.702
Educational capital	0.790	0.328	5.778	1	.016	**2.202**	1.157	4.192
Access to town	1.604	0.408	15.435	1	.000	**4.974**	2.234	11.073
prECI	1.404	0.497	7.969	1	.005	**4.072**	1.536	10.793
Preferred age of first birth	0.090	0.088	1.056	1	.304	1.094	0.921	1.300

D. Discussion

Encouraging delayed reproduction in Tsimane women may be especially important for their educational attainment. The average Tsimane woman marries at 16, and once married rarely continues to attend school, and has her first child shortly after at around 18. While for men, who are on average almost 4 years older than their wives, completing high school before marriage and becoming fathers is rarely an issue (assuming high school is available in their village or they can relocate). An additional concern is that the median age of first birth for women may be declining (see Chapter II), despite women stating a preferred age of first birth for daughters that is more than a year older than the average. Earlier reproduction brings with it a host of maternal and child health concerns, and may reduce women's autonomy and bargaining power within the marriage, limit economic growth by trapping women in more traditional roles, and enable higher fertility by extending women's reproductive lives. There is a real need to understand why Tsimane women, and women in similar populations, start their reproductive lives so early despite education initiatives.

1. Education alone may not encourage delayed reproduction

Greater access to schooling does not currently lead to older ages at first birth among Tsimane women. Nor does education directly encourage older preferred ages of first birth for children, despite encouraging greater educational aspirations for children – educational aspirations for children do not motivate any preferred delays in children's age of first birth. Instead, education encourages greater perceived returns to investments in daughters' educations, which in turn encourages older preferred ages of first birth for daughters. For sons, women's education may have the surprising effect of encouraging younger preferred ages of first birth, while having no effect on their perceived returns to educational investment in sons. However, women with greater perceived returns to investments in sons' educations prefer older ages of first birth for their sons. This suggests that perceiving there to be returns to investments in education, more so than education itself, may be key to encouraging delayed reproduction for both women and men.

It is surprising that there is not even a weak direct effect of women's educational capital on preferred age of first birth for daughters, and very surprising that there is perhaps a negative relationship for sons. More educated women are better able to understand community meetings where family planning is discussed, including the advantages to maternal and child health, and to reducing fertility, that are associated with older ages at first birth. More educated women are also better able to read family planning literature on their own, and converse with medical professionals and other non-Tsimane that may espouse the advantages of delaying first birth.

We were very surprised to find that more educated women trended toward preferring younger ages at first birth for sons. However, more educated women likely married more educated men or have more educated brothers, and may thus have more intimate knowledge of what the costs versus benefits of delaying first birth for an educated Tsimane man are. Given that there are advantages to high fertility, and that early reproduction encourages high fertility, Tsimane women may prefer high quality sons (i.e. highly educated sons) to start reproducing earlier, as a longer reproductive life means more children/grandchildren.

Furthermore, highly educated men may be considered better able to afford a family at a younger age as they may accrue resources through non-traditional means. Traditionally, men are expected to have built a house, have established agricultural fields, and be proficient hunters and fishermen before they have their first child – i.e. be able to feed a wife and child. However, through wage labor, which may be perceived as more accessible to more educated men, many of the resources required to care for a wife and child can be purchased, including paying other Tsimane to build a house, or develop and maintain agricultural fields. However, women who own more luxury items – a proxy for familial wealth – and have greater *access to town* preferred older ages of first birth for sons. See below (Sons vs. Daughters) for a discussion of these results.

2. Returns to investments in education may be needed before women delay their reproduction.

The Tsimane have low socioeconomic mobility, limited access to the labor market and low value within it. The education available to the Tsimane is also of low quality with only the larger villages having high schools. Further education is available ranging from monthly adult education classes in the larger villages, to Masters in engineering or medical degrees.

However, the later options require living far from home for extended periods of time. Few Tsimane families can afford to pay the associated cost of living or school expenses. There are government grants available to help offset the cost; but, very few Tsimane have good enough educations to be awarded these grants.

Women face the additional issues of cultural cloistering, negative gossip for those that do venture beyond designated traditional roles, generally lower educational attainment, and fewer opportunities to learn and improve Spanish speaking fluency and literacy. Tsimane women are more trapped in their traditional roles than Tsimane men. Within the more traditional role framework, success, adult status and independence, especially for women, are tied to reproductive achievements. Furthermore, from a parental point of view, marrying off daughters reduces the number of dependents and brings in the labor of sons-in-law. Encouraging early reproduction also increases the reproductive life span, and thus fertility, allowing for larger kin networks which enable greater influence, and better meets the need for child labor and care in old age. Consequently, it was unsurprising that perceived returns to investments in children's educational capital had to be high to encourage preferences for delayed reproduction in children – Why delay reproduction when there are no economic, social or political advantages to doing so?

This is supported by *access to wage labor for women* – a composite variable of whether women thought Tsimane women can earn money – also being positively associated with preferred age of first birth for daughters. And, women with greater *access to town* -- likely an indicator of autonomy, and exposure to and interest in the market – perceived returns to investments in children's educational capital to be higher.

3. Sons vs. Daughters?

We suggest again (see Chapter II) that preferences for children are sex specific and influenced by factors specific to the sex of the child in question. Women's preferred ages of first birth for sons were on average 2.5 years older than their preferred ages for daughters. While: (1) women's educational attainment lowered preferred age of first birth for sons, but had no direct effect for daughters; (2) women that thought wage labor was accessible to women preferred older ages of first birth for daughters, but accessibility of wage labor for men had no effect on preferred age of first birth for sons; and (3) women from households with more luxury items preferred older ages of first birth for sons only.

Access to wage labor for men may have had no effect on preferred age of first birth for sons as nearly all Tsimane men earn money either through wage labor or selling agricultural goods. However, Tsimane women independently earning money is a rarity. Women often earn money by selling produce or making and selling woven roof panels; however, these are normally familial projects and the money is considered the families or the head of households (usually her father or husband). Most available labor is manual, physically intensive and more difficult for a woman to excel at, and Tsimane culture generally cloisters women. Consequently, believing women can join the labor market and earn money is a big step toward valuing women as more than mothers. Especially, given that women face a greater opportunity cost of joining the labor market than men.

Ownership of luxury items may have been associated with older preferred ages of first birth for sons, but had no effect on preferred age of first birth for daughters, because unmarried sons often earn money for their natal families, and thus help purchase luxury items for the family. Delaying when sons marry and become fathers increases the amount of time a son is earning money for his natal family. Tsimane women's contributions to household wealth, on the other hand, are relatively low and daughters are generally considered a financial burden.

> *"Better to have sons. Sons are more important. Daughters are less important. Sons make [agricultural fields] and work for money. Daughters only with their mothers. So the family will have little food or money [if have to many daughters]."*
> 26 year old mother of five from a near town community

However, there was some overlap between the sexes. Women with greater access to town had greater prECI for both sons and daughters than women with lower access to town, and offspring sex did not moderate this effect. This may suggest that exposure to the market economy generally increases the perceived viability of non-traditional lives for both men and women. Also, for both sons and daughters, women with greater prECI for children preferred older ages of first birth for their children than women who perceived the returns to be low. This supports our idea that age at first birth is unlikely to increase unless there are positive returns to investing in education and joining the labor market.

4. Educational aspiration and preferred age at first birth

Women's preferred ages at first birth for their children were not associated with their educational aspirations for their children, despite some overlap in the factors affecting both. However, the relationship between women's *educational capital* and their educational aspirations for their children were much more as expected than our findings for preferred age of first birth.

More educated women had greater educational aspirations for their children. This effect was direct for sons and partially mediated by prECI for daughters. For both sexes, greater prECI for children encouraged higher educational aspirations for children. Also, prECI for children partially mediated the positive association between *access to town* and educational aspirations for children.

Educational aspirations for children have been shown to have a positive association with children's educational attainment in other populations. It is possible preferring greater educational attainment for children may lead to older ages of first birth for children, independently of preferred ages of first birth for children.

Interestingly, none of the predictors of educational aspirations for children were moderated by offspring sex. This may suggest that education has the blanket effect of increasing educational aspirations for children despite the returns to investments in educational capital varying by sex.

E. Summary

Our finding, that in some populations encouraging positive returns to investment in educational capital may be more important for delaying reproduction than education itself, supports the economic theory of fertility decline, and that women's prestige within the family must be decoupled from their reproductive achievements. Individuals are unlikely to forgo earlier reproduction in favour of investing in their education and joining the labor market when the opportunity costs of childbearing remain low, and their status within the family and their community remains linked to their reproduction.

This is especially true for women who bear a greater opportunity cost to childbearing. It is often easier for men to obtain education and access to the labor market. This may delay when a man marries and has his first child, but he is likely, especially in a society like the Tsimane where a wife's value is so strongly linked to her reproductive value, to still choose a young wife. This increase in age gap between husband and wife may reduce women's autonomy and bargaining power within the marriage, and is unlikely to encourage fertility decline.

To increase women's ages of first birth, thus reducing their reproductive life spans and setting the groundwork for reducing fertility, parents and society need to value women's education and there need to be payoffs to women being educated and delaying first birth. For the Tsimane, this needs to include viable, accessible, and respected labor opportunities for women that are long-term and can reliably help support their families. A cultural shift in how women's status and success is measured is also key. Tsimane women need to be valued as more than mothers and homemakers.

Realistically these changes are a long-way from happening, and hindered by factors outside the Tsimane's control. However, local government and non-profit organizations striving to reduce teenage pregnancy and fertility in the Tsimane, and in similar populations, may find more success if they encourage returns to investments in women's educational capital. For example: (1) create work co-ops in villages for the women; (2) encourage local businesses to employ the women; and (3) espouse the advantages of women in the labour force rather than just the advantages of educating women and reducing fertility which are often health or child focused.

F. Future Research

The negative trend between women's educational capital and preferred age of first birth for sons was surprising and concerning. An obvious issue with this finding is our small sample size. Future work should have a larger sample size to ensure this result was not spurious, and a large qualitative component to investigate why women perceive older or younger ages of first birth to be ideal. A cross-cultural component, even if only with neighbouring indigenous groups, would highlight if this issue is unique to the Tsimane or common among populations where the returns to investments in educational capital are low.

Women are not the only parent influencing their children's behaviours. Future research should examine how men's education and reproductive preferences for their children are affected by education and integration in to the market economy. Exploring, within family units, whether men's or women's preferences have greater effects on children's educational attainment and reproductive behaviour would also be of interest.

IV. Teenage Pregnancy compromises maternal growth but not reproductive success among the Tsimane, Bolivian forager-famers.

This chapter is co-authored with Geni Garcia, Aaron Blackwell, Hillard Kaplan and Michael Gurven. The author of this dissertation proposed the work contained here from her experience mentoring Garcia through an undergraduate honors thesis at UCSB that explored teenage pregnancy among the Tsimane. Kaplan and Gurven as directors of the Tsimane Health and Life History Project provided the Tsimane data used herein. Blackwell provided Tsimane growth data, and invaluable statistical advice and training. The author of this dissertation proposed all hypotheses tested herein. The analyses, writing, and figures contained in this chapter are the work of the author of this dissertation.

A. Introduction

Adolescent reproduction is a global concern with millions spent on programs to educate and protect at-risk-girls every year (Chandra-Mouli et al., 2013; UNFPA, 2013). Adolescent reproduction accounts for 11% of annual births worldwide. Each year, 16 million women aged 15-19 and one million aged ≤14 give birth (World Health Organization, 2012),facing higher risks of maternal death, violence, disability, and violations of rights to education, employment and reproductive health than women who delay their AFR until age ≥20 (Chandra-Mouli et al., 2013; Loaiza & Liang, 2013). Approximately 95% of these women are in low-income countries where the average age at first reproduction (AFR) ranges from 18.1 in Niger to 24.6 in the Comoros (CIA World Factbook, 2014). AFR also varies tremendously within nations. In Bolivia, in 2008, average AFR ranged from 19.0 in Beni (a relatively impoverished department) to 21.7 in La Paz (a relatively wealthy department) (Ramiro and Ochoa, 2009); and in the USA, in 2009, average AFR ranged from 22.6 in Mississippi to 27.7 in Massachusetts (Mathews et al, 2009). Among indigenous populations average AFR ranges from a low of 15.5 among the Pumé of Venezuela to a high of 25.7 among the Gainj and Asai of New Guinea, with many indigenous women multiparous before age 20 (Kramer & Greaves, 2010; Kramer & Lancaster, 2010; Walker et al., 2006).

There is extensive research on the negative consequences of adolescent reproduction (Agustin Conde-Agudelo et al., 2005; Gibbs et al., 2012; Gunderson et al., 2012; Schnall et al., 1994; World Health Organization, 2012; Zabin & Kiragu, 1998), yet a growing literature suggests that adolescent reproduction is a viable and evolutionary normative strategy under conditions of resource stress, psychological stress, paternal absence, and/or high extrinsic mortality (Chisholm et al., 1993; Ellis, 2004; Geronimus, 1996; Kramer & Lancaster, 2010; Migliano, Vinicius, & Lahr, 2007; Walker et al., 2006; Wilson & Daly, 1997), suggesting a potential disconnect between evolutionary fitness and human well-being. Variation in AFR may reflect alternate life history strategies, in which women optimize reproductive effort in light of resource constraints and extrinsic mortality and morbidity risks. Prevailing environmental conditions and cultural norms influence women's physiological and behavioral control of their reproductive effort (Ellison, 2001; Mace, 2000). Given the diversity of environments and cultures humans inhabit it is not surprising there is such variation in AFR. What is surprising, given the associated costs and risks (discussed below), is the commonality of adolescent reproduction (≤19 years), particularly precocious reproduction (reproduction before cessation of growth) in non-Western societies, and that precocious sexual maturity and adolescent reproduction may be our ancestral norm (Dean, 2006; Kramer & Greaves, 2010).

Here we examine variation in AFR within a single population, investigate precocious reproduction as a life history strategy, and explore the directionality and causal relationship of the growth-reproduction tradeoff. Studies on the causes of adolescent reproduction in humans, and its consequences for maternal growth and reproductive success, have mostly looked across populations and focused on developed or developing urban populations with better health and nutritional stability, and vastly different socioeconomic situations than were found in our ancestral environments. The few studies among indigenous groups have had relatively low sample sizes that do not allow for detailed within population comparisons of different life history strategies. We investigate the aforementioned among 2631 women born 1920 to 2002 in an indigenous population, the Tsimane. The Tsimane are a culturally homogenous, energy-limited, natural fertility population of Bolivian forager-farmers with high infant and adult mortality (Gurven, 2012b; Gurven et al., 2007), low income (estimated average annual income was US$332 per Tsimane man in 2002 compared to US$980 per Bolivian (Godoy et al., 2005)), limited modern health care and prenatal care, continued socioeconomic importance of social networks built around kin, and limited use of material technology and market goods. The delay between sexual maturity and exposure to conception is small. Average age at menarche is 13.9, while median age at first intercourse is 15, with 99% sexually active by 18 (Stieglitz et al., 2012; Walker et al., 2006). Furthermore, contraceptive use is extremely rare, and marriage and pregnancy in adolescence are culturally sanctioned and not associated with negative socioeconomic outcomes. The Tsimane are, thus, an ideal population to observe potential trade-offs between growth and reproduction.

1. Age at First Reproduction and Maternal Growth

Mammalian females face trade-offs among investment of energy in growth, self-maintenance (e.g. immune function and tissue repair) and reproduction (Chisholm et al., 1993; K. Hill & Kaplan, 1999; Mace, 2000). Natural selection should favor mechanisms enabling females to monitor their environments and apportion their finite resources among these competing alternatives accordingly (D. Coall et al., 2012). How females allocate their finite resources results in characteristic growth, fertility, and mortality patterns across their lifespans (i.e. life histories). Greater reproductive effort necessitates lower allocation of resources to self-investment in growth and maintenance, leading to lower maternal survivorship and investment in future reproduction.

There is a general assumption that reproduction in mammals occurs only after cessation of growth or triggers the end of maternal growth. However, a number of mammals, including, cattle, guinea pigs, horses, humans, voles, pigs, rats, rhesus macaques, Tasmanian devils, and flying squirrels, are known to be fecund before adult size is reached (Fokidis, Risch, & Glenn, 2007; Jones et al., 2008; Kraus, Trillmich, & Künkele, 2005; Nettle et al., 2010; Sukanich, Rogers, & McDonald, 1986; Tkadlec & Zejda, 1995). Reproduction in still-growing females, and growth during and after primigravidity, occur but are limited by maternal-fetal competition for resources, such that AFR and adult body size positively correlate (Alves, Cisneiros, Dutra, & Pinto, 2012; Rah et al., 2008; Scholl, 2007; Scholl, Hediger, & Schall, 1997; Scholl, Hediger, Schall, Khoo, & Fischer, 1994; Stevens-Simon & McAnarney, 1993).

Women's adult body size has two primary components: (1) skeletal size, e.g. proxied by standing height; and (2) fat and muscle mass, e.g. proxied by weight-for-height. Adult skeletal size is determined by genetics, prenatal maternal effects, pre- and post-pubescent health and nutrition, reproductive effort, and age at cessation of skeletal growth (Dewey & Begum, 2011; Pollet & Nettle, 2008; Sear, 2004; Tanner, Whitehouse, & Takaishi, 1966). Investment in fat stores and muscle mass are ongoing, positively correlated with pre- and post-pubescent health and nutrition, and negatively correlated with reproductive effort. Women with better pre-pubescent health and nutrition have faster childhood growth, achieve puberty earlier and can have an earlier AFR. All else being equal, subsequent growth depends on the level of reproductive effort during adolescence, with multiparous adolescents experiencing the least growth (Rah et al., 2008; Scholl et al., 1994). It remains unclear whether the reduced adult height of adolescent mothers is a factor of their fast life history strategies -- earlier investment in growth and growth asymptote, and consequently earlier reduction in investment in growth -- or due to reproduction competing for maternal resources and consequently limiting maternal growth. Given post-partum growth and the effects of multiparity in adolescence we suspect the later. **Hypothesis 1 (H1): Early AFR reduces the mother's total investment in self-growth such that women with comparable pre-pubescent condition but later AFR achieve larger adult size.**

2. Age at First Reproduction and Fertility

Across species life histories are calibrated to local mortality rates, and within species variation in life expectancy is strongly associated with individual variation in life history traits (Harvey & Zammuto, 1985; Promislow & Harvey, 1990). Original assumptions of a log linear relationship between life expectancy and AFR are now disputed (Charnov, 2001), but the general pattern holds such that under high mortality environments, with correspondingly short life expectancies, lifecycles are compressed into shorter time frames (Harvey & Zammuto, 1985; K. Hill & Kaplan, 1999; Low et al., 2008, 2013; Mace, 2000). These fast life histories are characterized by relatively rapid growth, and earlier peak growth, sexual maturity and reproduction (Williams, 1966). Across human populations, life expectancy is positively related to AFR, suggesting adolescent reproduction may be optimal under conditions of high extrinsic mortality risk (Chisholm et al., 1993; Griskevicius, Delton, Robertson, & Tybur, 2011; Krupp, 2012; Low, Parker, Hazel, & Welch, 2013; Migliano, Vinicius, & Lahr, 2007; Nettle, 2010; Walker et al., 2006; Wilson & Daly, 1997). Childhood mortality risk may have a stronger influence on life history than current mortality risk (Placek & Quinlan, 2012); whether this is due to calibration in childhood to expected future environments or childhood adversary having long-lasting negative impacts on the soma that necessitate adjusted life history strategies is debatable (Nettle, Frankenhuis, & Rickard, 2013).

The high rates of adolescent pregnancy seen in low-income countries and indigenous populations are likely driven by extrinsic mortality encouraging relatively fast life history strategies (Kramer & Greaves, 2010; Kramer & Lancaster, 2010; Walker et al., 2006; World Health Organization, 2012). These are populations with high infant and child mortality, and high fertility, where adolescent pregnancy is supported by the availability of allo-mothers, sharing networks, and cultural sanction of early reproduction. These conditions are likely similar to our ancestral state. Under these conditions adolescent reproduction should lead to higher lifetime fertility and a greater marginal benefit toward fitness for each reproductive bout compared to women with later AFR. **Hypothesis 2 (H2): among a population with high infant and child mortality rates, earlier AFR will be positively associated with fertility.**

3. Age at First Reproduction and Reproductive Success

Adolescence is a period of continued skeletal growth, including our species specific adolescent growth spurt that takes off from ages 10 to 14 in women (Bogin, 1999; Tanner et al., 1966), building of fat stores, including the species and sex specific gluteal fat stores, important in fetal development and lactation (Lassek & Gaulin, 2007), cognitive and intellectual development including executive functions and improved processing speed (which levels off at ~ age 15) (Keating & Clark, 1980; Mylod, Whitman, & Borkowski, 1997; Sieving & Stevens, 2000), psychosocial development, including developing a sense of self and autonomy, and peer over family emotional support networks (Sieving & Stevens, 2000), and accruement of social, ecological and economic skills and resources associated with success in adulthood (Gomez & Santolaya, 2005; Zabin & Kiragu, 1998). Diverting energy to reproduction during adolescence is associated with numerous negative outcomes, including higher risks of maternal and perinatal mortality due to incomplete skeletal maturity (Agustin Conde-Agudelo et al., 2005; Thaithae & Thato, 2011; Wells, DeSilva, & Stock, 2012), greater neonatal and infant mortality (Coyne, Långström, Lichtenstein, & D'Onofrio, 2013; Gibbs et al., 2012), higher rates of preterm birth, low birth weight and asphyxia (Alves, Siqueira, Melo, & Figueiroa, 2013; Gibbs et al., 2012; Ryan et al., 2011), and poorer socioeconomic outcomes for both mothers and children (Chandra-Mouli, Camacho, & Michaud, 2013; Scholl, 2007; UNFPA, 2013; World Health Organization, 2012). These negative pregnancy outcomes weigh against the potential total fertility benefits from starting reproduction at an early age.

However, adolescent reproduction is common in low-income countries and the norm for many indigenous populations (Kramer & Lancaster, 2010; World Health Organization, 2012). These are populations where poor childhood health and nutrition are associated with stunting and prolonged growth and development through adolescence into early adulthood (Dewey & Begum, 2011; Foster et al., 2005). High extrinsic mortality may encourage earlier AFR despite the costs. Furthermore, many of these negative outcomes only occur: (1) with extreme skeletally immature women, commonly women with AFR ≤ 15 years, due to greater obstetric risk and maternal-fetal resource competition (Kramer & Lancaster, 2010); (2) in higher-income populations where education and extra-somatic wealth contribute more to socio-economic success (discussed below; Kaplan, et al 2002); and (3) where most adolescent reproduction occurs outside of stable unions, with low maternal familial support, and cultural disapproval (Coall et al., 2012; Coyne et al., 2013; Grogger & Bronars, 1993; Kramer & Lancaster, 2010; Sagili et al, 2012).

Within a population with more somatic and traditional markers of success, where women have limited opportunities outside marriage and motherhood, early and stable marriages are common, adolescent reproduction normal and supported by kin and cultural sanction, the negative consequences of adolescent reproduction should be largely biological. The negative biological consequences of adolescent reproduction are not associated with maternal age, but rather developmental immaturity (Altman, 1986). Adolescence in humans is a prolonged period of continued growth and development that stretches across ~10 years. Women ≤ 15 years are likely developmentally immature; however, women in their mid-teens while not fully grown have likely completed most of their growth. Among the Pumé of Venezuela, reproduction in the mid-teens was found to minimize the cost of early reproduction, specifically infant mortality compared to earlier AFR, while maximizing the reproductive life span compared to later AFR (Kramer, 2008). **Hypothesis 3 (H3): although, precocious reproduction can be optimal, extreme precocious reproduction (AFR ≤15years) is likely not. Women with AFR ≤15years should experience the greatest costs of concurrent investment in growth and reproduction, including higher infant mortality, and ultimately lower reproductive success than women with later AFR.**

4. Childhood Condition and Age at First Reproduction

In addition to mortality, AFR is also related to morbidity, resource stress, psychological stress, and paternal and/or maternal absence (Clutterbuck, Adams, & Nettle, 2014; D. Coall et al., 2012; Ellis, 2004; Geronimus, 1996; Nettle et al., 2011; Wilson & Daly, 1997). All else being equal, fitness-maximizing organisms with access to more resources, i.e. a greater energy budget, can invest more in reproduction. In humans, earlier age at menarche is associated with better childhood nutrition and health due to greater resource access (Ellis, 2004; Ellison, 2001). Age at first reproduction, though, can be positively coupled to resource access. Improved resource access may increase self-investment in embodied capital (i.e. size, skill, and knowledge) to enhance opportunity for socioeconomic success, which delays AFR, despite earlier menarche (Kaplan, Lancaster, Tucker, & Anderson, 2002; Mason, 1997; Newson, Postmes, Lea, & Webley, 2005). Furthermore, in low-mortality and resource-rich environments, children are perceived by individuals as costlier to produce because of the investments in embodied capital required for their socioeconomic success as adults (Kaplan et al., 2002). Most indigenous populations have low socioeconomic status, limited socioeconomic mobility, and low within group socioeconomic inequality. In such populations, cost of children is perceived as relatively low and motivation to delay AFR to allow women to accrue more embodied capital is minimal (McAllister, Gurven, Kaplan, & Stieglitz, 2012). **Hypothesis 4 (H4): if motivation to delay AFR is low, within group variation in AFR is due mainly to individual variation in resource access affecting women's childhood health and nutrition, and thus growth and adolescent fecundity.**

5. Study Goals

Here we document Tsimane fertility behavior with a focus on the effects of AFR on maternal growth and reproductive success. We present a longitudinal study suggesting variation in life history strategy within a single population with relatively homogenous mortality risk. We introduce a path model assessing the relationship between precocious investment in growth and the onset of menarche, AFR, and adult height (a proxy for completed amount of investment in growth) (H1). We explore early AFR as part of an optimal strategy in a high mortality environment (H2) and how childhood condition (proxied by childhood height–for-age and BMI-for-age) predicts AFR within this population (H3). We test whether extreme precocious reproduction (AFR ≤ 15 years) is sub-optimal (proxied by higher infant mortality and lower reproductive success) compared to later adolescent (AFR 16-19 years) and adult (AFR ≥20 years) first reproduction (H4).

B. Materials and Methods

1. Data Collection

The height and reproductive data presented here were collected amongst the Tsimane by the Tsimane Health and Life History Project (THLHP). The heights and weights of 2401 women born between the years of 1952 and 2002 were measured using a portable stadiometer and Tanita weight scale between 2002 to 2012. The mean ±SD for repeat measures of these women was 3.51 ±2.74. The heights of women pregnant at time of measurement were included, and gestational stage and pregnancy outcome noted. The demographic interviews and methods used to collect reproductive data and ascribe ages are described in detail in Gurven et al (2007). Reproductive data has been systematically updated through bi-annual censuses and medical checkups by THLHP personnel. To summarize, reproductive events from 2002 to 2005 were ascribed from retrospective reproductive histories of interviewees that are cross-validated with those of their parents, children, siblings and spouse where possible to assign estimated order of and timing of events. Reproductive events from 2006 to 2012 are taken from the bi-annual censuses and medical checkups. Age at reproductive event, including AFR, were assigned from parent and child years of birth. It is not taboo to talk about miscarriages, still births, neonate or infant deaths among the Tsimane, although these numbers may be under reported to male interviewers, due to recall bias or due to being unknown by corroborating family members absent at time of event. In the demographic interviews miscarriages were listed and assigned a year based on order of event compared to other reproductive events, and maternal self-report on number of months from previous birth and to next birth. To calculate total fertility rate, and the reproductive success of post-reproductive women the reproductive histories of an additional 230 women born 1920 to 1990 are considered. Anthropometrics for these women were not available.

2. Study Population

The Tsimane are lowland Amerindian forager-farmers living in the Beni Department of Bolivia. Two thirds of their diet is from swidden horticulture that is supplemented with hunting, fishing and gathering (Martin et al. 2012). The Tsimane are relatively culturally homogenous. Variation in education, Spanish fluency, distance to the nearest town (San Borja, population ~24,000), and contact with non-Tsimane are low and associated with variation in individual levels of market integration and participation, and access to modern healthcare. Market participation, especially wage labor, is dominated by men; for most women non-traditional life-ways -- options beyond motherhood and household labor -- are unavailable. Tsimane have high fertility (total fertility rate = 9) and infant mortality (13%) (Gurven, 2012b), both of which co-vary with distance to town.

Mean age at menarche is 12.95 ± 0.96. Post-menarche Tsimane women are considered marriageable, but on average marry 3.07 ±1.95 yrs after menarche, with 70% married before their 17^{th} birthday. Husbands are 3.81±4.24 years older than wives. Marriages are often arranged by kin, with cross-cousin marriages preferred. Both polygyny and polyandry are culturally sanctioned, but rare (polygyny < 10% usually sororal; fraternal polyandry by one Tsimane woman). There are no formal marriage ceremonies despite marriage being a socially recognized convention. A couple is considered married after they sleep together in the same house for an extended period of time; although, a small celebration among close kin and neighbors is becoming increasingly common. Pre-marital sex does occur but can leave the woman stigmatized if discovered and if pregnant a marriage may be forced. Unwed mothers remain with their natal household, and divorced and widowed women often return to their natal household. These women and their children are welcomed but considered a burden. Unwed, widowed and divorced women with children often leave their children with a close relative (parents, grandmother, sister) when they (re)marry.

Post-marital residence is usually matrilocal for several years. The farming and hunting labor of sons-in-law and matrilineal help with primigravidity are highly valued. After this period marital residence is a mix of matrilocal, patrilocal and neolocal. Approximately 20% of marriages end in divorce, with most divorces occurring early in marriage (median age a woman remarries is 21 years). The teen birth rate was 12.6 births/1,000 women ages 10-14 and 386.4 births/1,000 women ages 15-19 in 2002 to 2007. This is five-fold greater than the equivalent rate in Bolivia in 2008 (76.9/1,000 women aged 15-19, DHS), and four to ten-fold higher than among U.S. women (3.26 births/1,000 women for ages 10-14,41.1 births/1,000 women ages 15-19, 2002 to 2007 (Child Trends DataBank, 2013). Mean AFR is 18.07 ± 2.82; with 37% of Tsimane women uniparous and 35% multiparous by 20 years. Adolescent reproduction is normative in this population: 95% confidence intervals of distribution are 17.93 – 18.20 for AFR (*n*=1729). Among the Tsimane, the costs of precocious reproduction are likely reduced by high access to large kin support networks and food sharing. Also, motivation to delay reproduction is low as women's education and career options are extremely limited, and women's social status remains linked to their somatic investments (both own physical condition and reproductive history) (McAllister, Gurven, Kaplan, & Stieglitz, 2012; Veile, Martin, McAllister, & Gurven, 2014).

The Tsimane are a natural fertility population in which modern methods of fertility control are rare. The total fertility rate (TFR) is 9.55 for women born 1945 to 1990, with a mean ±SD interbirth interval following previous child surviving to one year of 29.64 ±9.99 months and following previous child dying before one year of 23.02 ±12.03 months. There is evidence that fertility is increasing in younger cohorts, despite growing desire for small completed fertility, as the mean ±SD fertility of women aged 45+ at time of interview was only 8.41±3.33. Motivation to reduce fertility is low as family size is a measure is positively associated with success for both men and women, and children are seen to bolster the kin network and thus sociopolitical power of their parents, and provide valuable labor and care as their parents age.

For women aged 45+ mean ±SD age at last child was 40.65±3.26 following 21.99±5.23 years of consecutive pregnancies and lactation since first birth, with a mean interbirth interval of 32.05 ±10.24 months (32.46 ±10.24 months if the previous child survived to age one; 25.19 ±13.57 if the previous child died during infancy). Maternal mortality among the Tsimane is estimated at 702 deaths per 100,000 live births (from 1972 to 2012 30 deaths due to complications of pregnancy or child birth out of 4275 live births).

2.1. Age at Event

Age at event data is taken from the THLHP demographic interviews and bi-annual census and health interviews, see Gurven et al 2007 for details (*n* = 1335 women with anthropometric data). Due to recall decline over time, self-reported age at menarche is only considered for women who were ≤30 years at interview (*n* = 363). Age at first marriage is taken from the 2002 to 2005 demographic interviews, in which men and women were asked how old they were when they married or how many years from their marriage to AFR. Age at first marriage is considered for all women whose self-reported age at first marriage was not more recent than the first birth associated with the union (n = 255). For AFR (n = 1335) we include failed pregnancies (miscarriages and still births) as they indicate investment in reproduction and are a substantial cost to the mother. Women's AFR were calculated as mother's year of birth subtracted from first born child's year of birth for live births. For failed pregnancies mother's year of birth was subtracted from the year of miscarriage or still birth (n = 57).

2.2. Reproductive History

Women's total number of pregnancies, the timing and outcome of each pregnancy – used to assess reproductive behavior and success – are taken from the THLHP demographic interviews described in Gurven et al (2007). Women with known year of event for all pregnancies and births (n = 396 and risk years = 8583) were used to find the age specific fertility rate, and subsequently the total fertility rate, for all Tsimane women and for each AFR subgroup (AFR ≤ 15 n = 44, risk years = 1152; AFR 16-19 n = 261, risk years = 5181; AFR ≥ 20 n = 91, risk years = 2250). The total fertility rate, miscarriage rate, and infant and child mortality rates were checked against the reproductive outcomes of all pregnancies of post-reproductive women with accurate years of event for all pregnancies and births (AFR ≤ 15 n = 34; AFR 16-19 n = 139, AFR ≥ 20 n = 70). Husbands' reproductive histories are also taken from the THLHP demographic interviews to provide age discrepancies in AFR between Tsimane men and women (wife's AFR ≤ 15 n = 85; wife's AFR 16-19 n = 442, wife's AFR ≥ 20 n = 202).

2.3. Divorce Rates

Here women whose children's fathers and year of birth of children are known in the THLHP demographic interviews are considered (*n* = 1281). Women who were not widowed but have later children with a different man and no more children with the previous man are considered to have divorced (*n* = 261). Age at divorce is estimated as one year before birth of first child with new man.

2.4. Anthropometrics

Adult height (height at 20-45 years) for 1335 Tsimane women was taken from THLHP bi-annual anthropometric and health interviews. For women with multiple adult heights recorded the mean adult height is used. Heights recorded at < 20 years are considered non-adult as it is assumed some Tsimane women may still be growing, and heights recorded at > 45 years are excluded due to assumed height shrinkage with age. To compare growth in late childhood and early adolescence, and associated growth trajectories, heights and weights recorded when women were aged 10 to 20 years are used (*n* = 444, *obs.* = 1223).

2.5. Life History Strategy

To determine if earlier AFR is part of a fast life history strategy, and what may cause the observed discrepancies in AFR among Tsimane women, data from 444 women with adolescent (10-19 years) anthropometric data were used. These women were compared by AFR, body mass index and height. In addition, these women were binary coded as fast or slow growers before pregnancy based on whether their residual height-for-age at 10 to 12 years, standardized against Tsimane women's expected height for those ages, suggested they were short- or tall-for-age respectively. Path models utilizing multiple linear regressions were then used to assess the relationship between early growth trajectories and age at menarche, first birth and adult height (*n* = 380 (54 women had full data)). The reproductive efforts of 45 sister dyads (same mother and father), where one sister had AFR ≤ 15 and the other AFR ≥ 16 were also compared, to assess environmental versus genetic contributions to AFR and subsequent fertility.

C. Results

For many of the following analyses we partition women into three groups based on their AFR: early (AFR ≤15 (*n* = 170), mean AFR ±SD = 14.35 ±0.91, age range = 12-15 years), norm (AFR 16-19 (*n* = 784), mean AFR ±SD = 17.52 ±1.09) and late reproducers (AFR ≥20 (*n* = 381), mean AFR ±SD = 21.51 ±1.54, age range = 20-25 years). Early reproducers make up 13% of this subpopulation, norm 59% and late 28% (Figure 1). These AFR groups originate from groupings in the adolescent reproduction literature and analyses of Tsimane women with known adult heights (*n* = 1335), and are maintained for analyses with other subsets of Tsimane women. These divisions have both a cultural and biological basis. Age at first reproduction ≤ 15 years is not taboo among the Tsimane but it is considered young (unpublished data) with many early reproducers complaining they were too young, that their bodies were not ready and/or that their husbands and they had not accrued sufficient resources to start a family. Fifteen years is approximately one standard deviation from the population mean AFR (mean=18.25 ±SD2.60). Furthermore, reproduction at or before 15 years is associated with higher infant and maternal mortality in other populations (Chandra-Mouli et al., 2013; UNFPA, 2013; World Health Organization, 2012). Similarly, AFR ≥ 20 years is associated, in other populations with lower infant and maternal mortality, but is considered old for first birth among the Tsimane (unpublished data). The average reproductive characteristics of women in these groups are shown in Table 1.

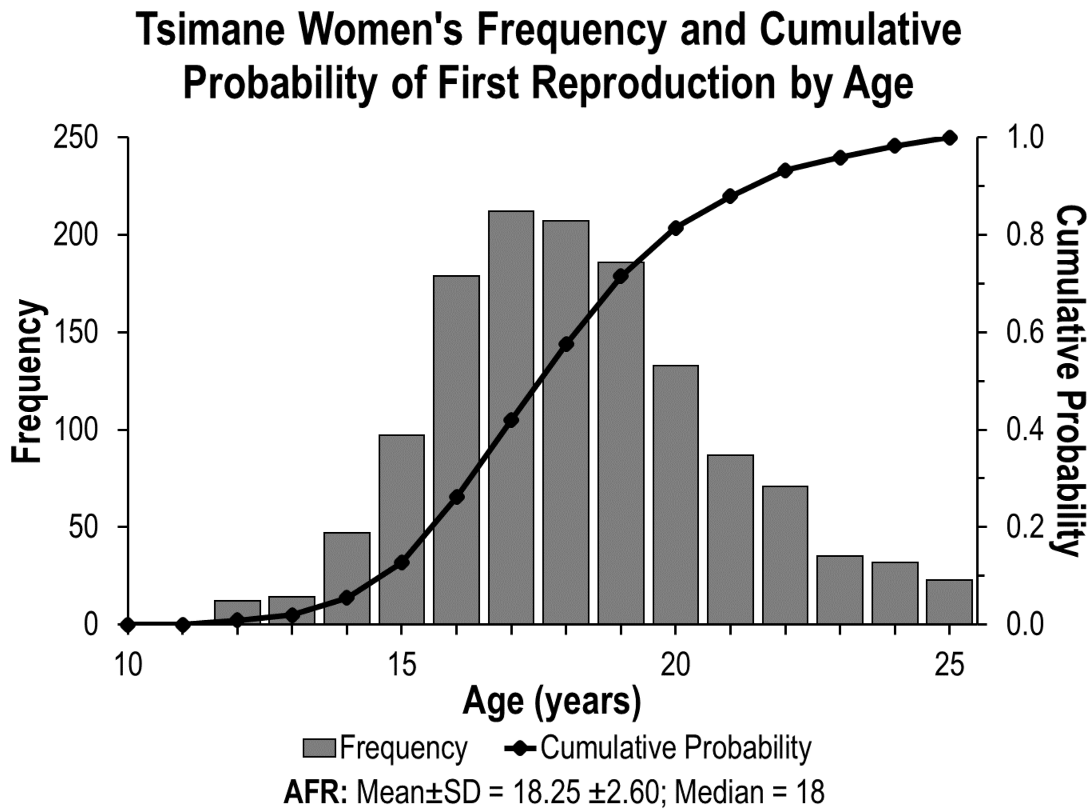


Figure 1: This graph is specific to the Tsimane women included in this study who had an adult height recorded (*n* = 1335). The bars show the distribution of age at first birth from ages 10 to 25 years (left axis), and the line the cumulative probability of fist birth for these women (right axis).

Table 1. Reproductive characteristics of the three AFR groups for Tsimane women born 1952 to 1992. Note the change in *n* are related to some women having incomplete data (not all women have a self-reported age at menarche) or not being applicable (e.g. for self-reported age at menarche only women ≤30 years are considered to reliably report this, and not all women experienced an infant death). All Tukey HSD mean differences are compared against AFR 12-15.

AFR (years)	Women's Year Born			**Reproductive Characteristics** Age at Menarche (yrs)			Age First Married (yrs)			Age at First Reproduction (yrs)		
	n	Mean ±SD	Mean Difference	*n*	Mean ±SD	Mean Difference	*n*	Mean ±SD	Mean Difference	*n*	Mean ±SD	Mean Difference
12-15	170	1978.75 ±9.63	-	45	12.80 ±1.18	-	20	14.60 ±1.27	-	170	14.35 ±0.91	-
16-19	784	1979.32 ±9.06	-0.57 ±0.76	123	12.88 ±0.88	-0.18 ±0.12	147	15.54 ±1.40	-0.94 ±0.43†	784	17.52 ±1.09	-3.16 ±0.10***
20-25	381	1976.05 ±8.69	2.69 ±0.83**	195	13.03 ±0.95	-0.10 ±0.13	88	17.09 ±2.38	-2.50 ±0.44***	381	21.51 ±1.54	-7.17 ±0.11***
All (12-25)	1335	1978.32 ±9.14	-	363	12.95 ±0.96	-	255	16.00 ±1.97	-	1335	18.25 ±2.60	-

†$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

AFR (years)	**Reproductive Characteristics Continued** Pregnancies-for-age			Interbirth Interval Previous Infant Lives (months)			Interbirth Interval Following Infant Death (months)			Sex Ratio (0 = daughter, 1 = son)		
	n	Mean ±SD	Mean Difference	*n*	Mean ±SD	Mean Difference	*n*	Mean ±SD	Mean Difference		Mean ±SD	Mean Difference
12-15	170	0.42 ±1.08	-	161	29.44 ±10.62	-	43	22.29 ±9.57	-	167	0.52 ±0.27	-
16-19	784	0.05 ±0.95	0.38 ±0.8***	522	29.54 ±10.03		124	23.77 ±13.61		775	0.51 ±0.29	
20-25	381	-0.29 ±0.99	0.71 ±0.09***	172	30.13 ±10.17		41	21.51 ±8.89		371	0.52 ±0.30	
All (12-25)	1335	-0.00 ±1.00	-	683	29.64 ±10.16	-	208	23.02 ±12.03	-	1313	0.52 ±0.29	-

†$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

1. AFR and Adult Height (H1)

Early reproduction does not terminate growth in stature: 79% of women with AFR ≤15 gained ≥2.5cm in height post-birth (paired t-test (t = 6.776, df = 33, p < 0.001)). However, AFR ≤15 women are shorter as adults than women with later AFR (Figure 2). For each year AFR is delayed a woman is 0.16cm taller (B(2, 1055) 0.062, p < 0.05). On average, AFR ≤15 women are 1.44 ± 0.38 cm shorter as adults than AFR 16-19 women and 1.35 ±0.41 cm shorter than AFR ≥20 women (Table 2 and Figure 3).

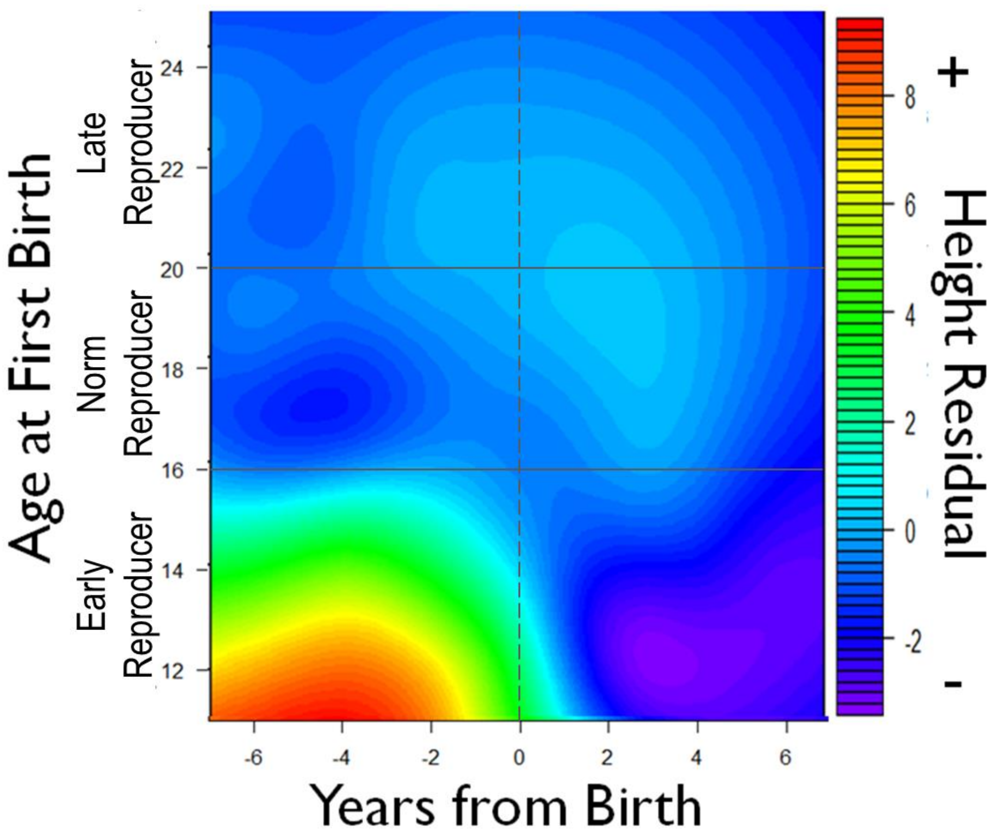


Figure 2. Shows height-for-age for a subset of Tsimane women with multiple height measurements recorded during childhood and adolescence (n = 313). The solid horizontal lines divide the graph by AFR (AFR ≤ 15 years (n = 76), AFR 16-19 years (n = 204), and AFR ≥ 20 years (n = 33). The vertical dashed line indicates first birth. The heat scale is shown to the right of the graph – purple/dark blue indicates short-for-age, pale blue indicates expected height-for-age, green through red indicates tall-for-age based on population averages. Women that reproduce at ≤15 years are tall-for-age before birth but short-for-age post-reproduction compared to women that reproduce later.

Table 2. Anthropometric characteristics of the three AFR phenotypes. The height residual is the difference between a woman's height and the expected height for a Tsimane woman of that age.

AFR (years)	Adult Anthropometric Characteristics Height (cm)			Height Residual		Weight (kg)			Body Mass Index	
	n	Mean ±SD	Mean Diff.	Mean ±SD	Mean Diff.	*n*	Mean ±SD	Mean Diff.	Mean ±SD	Mean Diff.
12-15	170	149.77 ±4.18	-	-1.39 ±4.18	-	164	54.75 ±7.64	-	24.10 ±3.14	-
16-19	784	151.21 ±4.52	-1.44 ±.38***	0.05 ±4.52	-1.44 ±.38***	748	54.81 ±7.94	-0.6 ±0.67	23.58 ±3.03	0.52 ±0.26
20-25	381	151.12 ±4.56	-1.35 ±0.41**	-0.04 ±4.56	-1.35 ±0.41**	360	54.66 ±7.53	0.09 ±0.73	23.66 ±3.06	0.44 ±0.29
All (12-15)	1335	151.00 ±4.52	-	-0.16 ±4.51	-	1272	54.76 ±7.78	-	23.67 ±3.05	-

†$p < 0.10$, **$p < 0.01$, ***$p < 0.001$

Figure 3. Mean adult height of Tsimane women (n = 1335) by age at first reproduction. One standard error is shown.

Comparing both women of similar pre-pubescent condition (n = 380) but different AFRs, and within sister dyads (assumedly similar access to resources during childhood) with discordant AFRs, supports reproduction compromising maternal growth. Early growth (tall-for-age between 10-12 years) is positively associated with adult height (Figure 4): women tall-for-age between 10-12 years who do not reproduce by 15 years are taller than average as adults. Comparing sister dyads with discordant AFR, age at menarche is similar among sisters, suggesting equivalent childhood growth, but AFR ≤ 15 women have shorter adult heights than their AFR ≥16 sisters (Table 3). There is a positive correlation between sisters, such that AFR ≤ 15 women who are taller than other AFR ≤ 15 women likely have AFR ≥ 16 sisters who are taller than other AFR ≥ 16 women. **Hypothesis 1 is supported. Early AFR**

reduces, but does not stop, maternal investment in self-growth. Women with comparable pre-pubescent condition but later AFR achieve larger adult size.

Table 3. Comparing reproductive and anthropometric variables across sister dyads (same mother and father, ≤ 6 year age gap).

		Age at First Reproduction		Paired t-test		Paired Samples Correlation
		≤ 15 years	≥ 16 years			
	n	Mean +SD	Mean +SD	*df*	t	r
Age at Menarche	19	12.95 +1.51	13.05 +1.08	18	-0.252	0.036
Mean Inter-birth Interval	23	29.17 +8.65	28.25 +6.15	23	0.481	0.240
Pregnancies-for-age	45	0.50 +1.10	0.04 +1.05	44	2.870**	0.502***
Adult Height	45	148.48 +4.27	150.63 +5.12	44	-2.825**	0.422**

**$p < 0.01$, ***$p < 0.001$

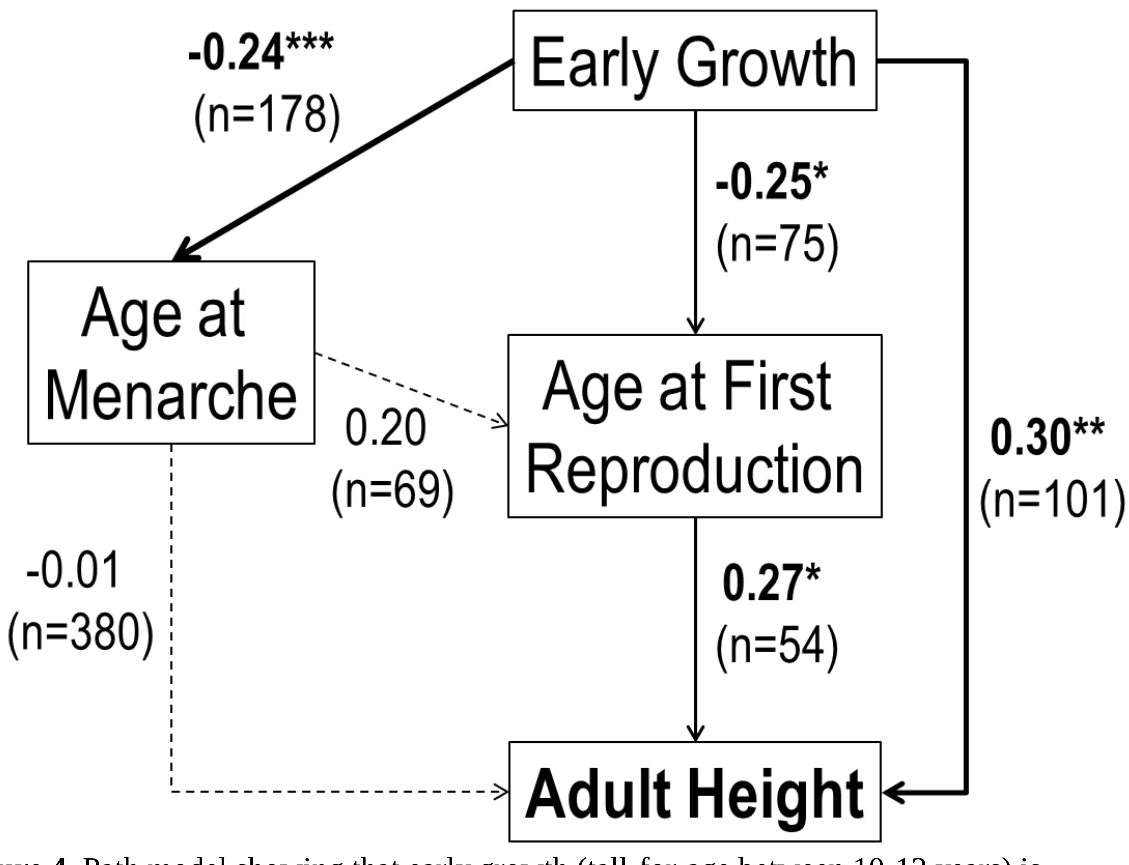


Figure 4. Path model showing that early growth (tall-for-age between 10-12 years) is associated with earlier ages at menarche and AFR, and greater adult height if AFR is delayed. Age at menarche is not associated with AFR or adult height. The standardized betas, sample size and *p-values* are shown. Bolded standardized betas have significant *p-values* (* < 0.05, ** < 0.01 and *** < 0.001). Total sample size was 380, with 54 women having data for all steps of the model.

2. AFR and Fertility (H2)

For each year AFR is delayed women have 0.08 fewer pregnancies-for-age (b^* = -0.22, $t(1335) = 7.94$, $p < 0.001$) and AFR explained 22% of the variation in lifetime fertility (R^2 = 0.22, $F(1, 1334) = 64.37$, $p < .001$). Supporting this, among a sample of Tsimane women with detailed reproductive histories early reproducers have greater predicted fertility: the TFR of AFR ≤15 women is 11.11, 1.20 more than AFR 16-19 women and 3.11 more than AFR ≥20 women (Table 4). This is further supported by the reproductive histories of Tsimane women aged ≥45 years -- women who have completed their reproduction. For each year AFR was delayed women aged ≥45 years had 0.41 fewer pregnancies (b^* = -0.52, $t(241) = 21.16$, $p < 0.001$) and AFR explained 28% of the variation in lifetime fertility ($R^2 = 0.28$, $F(1, 241) = 91.38$, $p < .001$). Women with AFR ≤15 aged ≥45 years had 1.95 more pregnancies than AFR 16-19 women, and 5.10 more pregnancies that AFR ≥20 women (Table 5; $F(2,240) = 39.659$, $p < 0.001$). Comparing sister dyads also suggests that AFR ≤15 women have more pregnancies-for-age than their AFR ≥16 years sisters (Table 3). **Hypothesis 2 is supported. Among Tsimane women AFR is negatively associated with fertility: women with younger AFR have more pregnancies and live births over their lifetimes than women with later AFR.**

Table 4. Age Specific Fertility Rate and Total Fertility Rate of Tsimane women born 1943 to 1990. Found using retrospective data and only live births. Women are separated by AFR. Number of risk years by AFR: $\leq$ 15 = 1152, 16-19 = 5181, 20-25 = 2250.

	Births per 1000 Women			
Age Group	**AFR ≤ 15**	**AFR 16 - 19**	**AFR 20 - 25**	**All Women**
10 - 14	68.18	NA	NA	6.98
15 - 19	485.00	299.52	NA	236.67
20 - 24	360.95	420.12	381.61	400.76
25 - 29	349.65	379.88	401.15	382.56
30 - 34	335.88	343.95	333.33	339.49
35 - 39	322.31	331.33	278.11	315.11
40 - 44	266.67	190.00	207.55	212.12
45 - 50	32.79	16.81	0.00	16.77
Total Fertility Rate	***11.11***	***9.91***	***8.00***	***9.55***

The larger TFR of AFR ≤15 women may be due to more years of reproduction because of both earlier onset and later termination of reproduction (Figure 5), rather than shorter interbirth intervals (Table 1). Early reproducers have earlier access to regular sex: women with AFR ≤15 marry 0.94 ±0.43 years earlier than AFR 16-19 women and 2.49 ±0.44 years earlier than AFR ≥20 women (Table 1; $F(2,252) = 27.25$, $p < 0.001$). Consequently, AFR ≤15 women experience their first birth 3.16 ±0.10 years earlier than AFR 16-19 women, and 7.17 ±0.11 years earlier than AFR ≥20 women (Table 1; $F(2,1142) = 2124.21$, $p < 0.001$); and 78% of women with AFR ≤15 are multiparous by 20 years compared to only 42% of AFR 16-19 women.

Supporting AFR ≤15 women having more years of reproduction, among the ≥45 year old women, AFR ≤15 women had both younger mean AFR ($F(2,240) = 226.355$, $p < 0.001$) and older mean age at last reproduction ($F(2,240) = 5.476$, $p = 0.005$) than women with later AFR, but equivalent interbirth intervals (Table 6). Sister dyads with divergent AFRs also have equivalent interbirth intervals (Table 3), further supporting the greater fertility of AFR ≤15 women being a result of comparatively longer reproductive lifespans not shorter interbirth intervals (Table 3). The drop in reproductive output of women with AFR ≤15 at 20-

24 years may be related to the higher divorce rate of AFR ≤15 women, and associated limited access to sex until re-marriage, rather than a difference in fecundity or active fertility control (Figure 4). The median age at remarriage is 21 years, and AFR ≤15 women are 1.63 times more likely to divorce their first husband and remarry than AFR 16-19 and 1.38 times more likely than AFR ≥20 women (Table 7).

Table 5. Lifetime reproductive activity for Tsimane women aged ≥45 years at time of interview by AFR group.

AFR	*n*	Number of Pregnancies		Miscarriages		Infant Deaths < 1 year		Child Deaths 1 - 5 years		Child Deaths 6 – 15 years		Children surviving to reproductive age	
		Mean ±SD	Mean Diff.	Rate ±SD	Mean Diff.	Rate ±SD	Mean Diff.	Rate ±SD	Mean Diff.	Rate ±SD	Mean Diff.	Mean ±SD	Mean Diff.
≤ 15	34	12.00 ±3.63	-	0.32 ±1.01	-	2.24 ±1.52	-	0.79 ±0.95	-	0.68 ±0.84	-	7.97 ±3.24	-
16-19	139	10.05 ±2.37	1.95**	0.29 ±0.70	0.04	1.56 ±1.56	0.67†	0.53 ±0.85	0.27	0.38 ±0.72	0.30†	7.29 ±2.91	0.68
≥ 20	70	6.90 ±3.79	5.10***	0.26 ±0.53	0.07	1.24 ±1.60	0.99**	0.40 ±0.67	0.39†	0.21 ±0.51	0.46**	4.79 ±3.38	3.18***
Total	243	9.42 ±3.48	-	0.28 ±0.71	-	1.56 ±1.59	-	0.53 ±0.82	-	0.37 ±0.70	-	6.67 ±3.32	-

†$p < 0.10$, **$p < 0.01$, ***$p < 0.001$

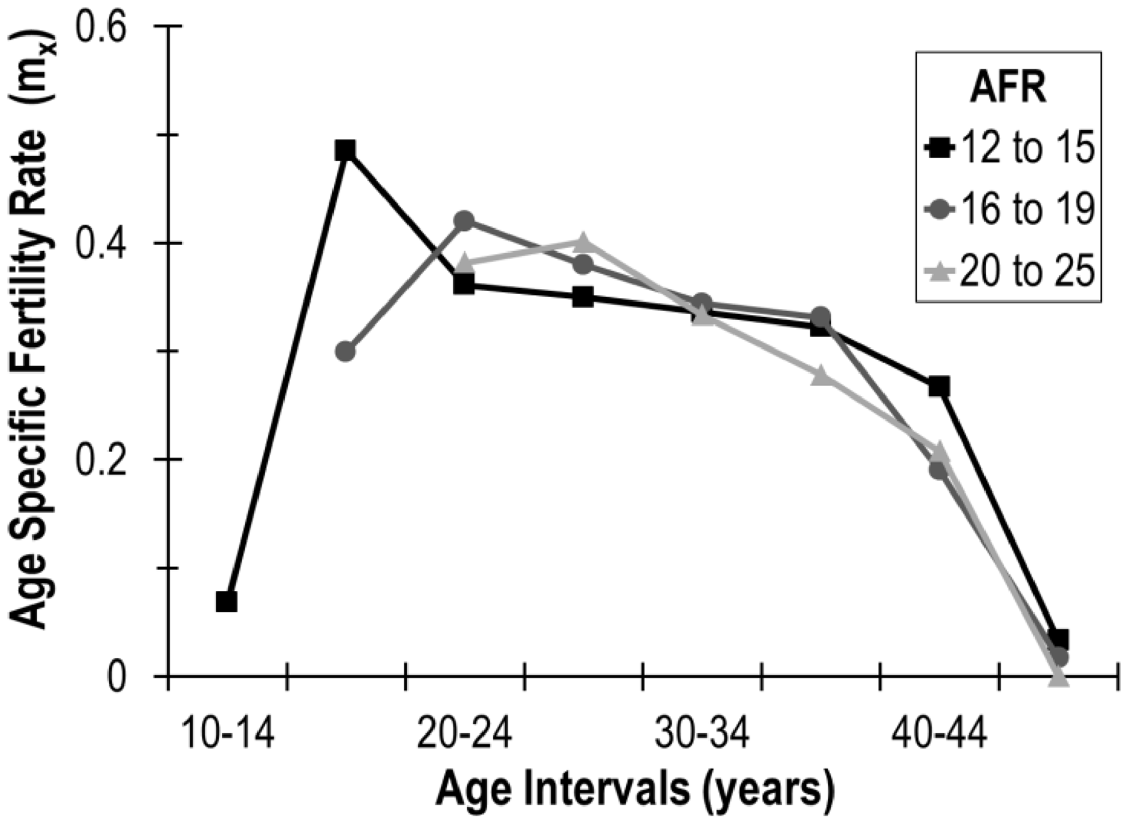


Figure 5. Age specific fertility rate within each five year period of a Tsimane woman's reproductive life, found using retrospective reproductive histories. Age at first reproduction is indicated. Number of risk years by AFR: ≤ 15 = 1152, 16-19 = 5181, 20-25 = 2250.

3. AFR and Reproductive Success (H3)

AFR ≤15 women trend toward being twice as likely to miscarry their first pregnancy compared to other women (Table 8; $F(2,1332) = 2.370$, $p = 0.094$). However, for women's first live birth their AFR did not influence their first born children's likelihood of surviving to adulthood, despite variation in childhood mortality risk (Table 7; All Child Deaths $F(2,1332) = 1.619$, $p = 0.198$).

Table 6. Reproductive characteristics for Tsimane women aged ≥45 years at time of interview by AFR group.

AFR	*n*	Year of Birth		Age at First Reproduction (years)		Age at Last Reproduction (years)		Reproductive Lifespan (years)		Inter-birth Interval (months)			Expected Number of Pregnancies (Reproductive Lifespan/IBI)
		Mean ±SD	Mean Diff.	Mean ±SD	Mean Diff.	Mean ±SD	Mean Diff.	Mean ±SD	Mean Diff.	*n*	Mean ±SD	Mean Diff.	
≤ 15	34	1944.82 ±10.83	-	14.56 ±0.70	-	42.32 ±3.04	-	27.41 ±3.53	-	32	32.77 ±9.78	-	***10.04***
16-19	139	1943.42 ±11.69	1.40 ±2.20	17.3 ±1.09	-2.74***	40.45 ±3.18	1.87**	23.09 ±3.26	4.32***	82	31.64 ±10.51	1.13	***8.76***
≥ 20	70	1945.63 ±11.38	-0.81 ±2.40	23.13 ±3.81	-8.57***	40.24 ±3.31	2.08**	17.17 ±5.31	10.24***	55	32.25 ±10.24	0.51	***6.39***
Total	243	1944.26 ±11.48	-	18.6 ±3.75	-	40.65 ±3.26	-	21.99 ±5.23	-		32.05 ±10.24	-	***8.23***

**$p < 0.01$, ***$p < 0.001$

Table 7. Divorce rate by women's AFR.

AFR Group	*n*	Divorce		t-test against AFR 12-15	
		n	Rate	*t*	*df*
≤ 15	135	40	29.63%	-	-
16-19	754	137	18.17%	3.08**	887
≥ 20	392	84	21.43%	1.94*	525
Total	1281	261	20.37%	-	-

*$p < 0.05$, **$p < 0.01$

Table 8. Reproductive outcomes of women's first pregnancies.

AFR (years)	Pregnancies	Miscarriages		Live Births	Child's Year Born	Sex (0=daughter, 1=son)		Child Deaths ≤ 1 year		Child Deaths 1-5 years		Child Deaths 6-15 years		Child Deaths All (0-15 years)	
	n	*n*	Rate	*n*	Mean ±SD	Sons	Sex Ratio	Deaths	Rate	Deaths	Rate	Deaths	Rate	Deaths	Rate
12-15	170	14	8.20%†	156	1993.10 ±9.81	76	0.47	10	6.41%	5	3.21%	4	2.56%	19	12.18%
16-19	784	29	3.70%	755	1996.85 ±8.99	415	0.54	65	8.61%	18	2.38%	4	0.53%	87	11.52%
20-25	381	14	3.70%	367	1997.57 ±9.08	201	0.53	23	6.27%	12	3.27%	3	0.82%	38	10.35%
All (12-25)	1335	57	4.30%	1278	1996.58 ±9.08	692	0.53	98	7.67%	35	2.74%	11	0.86%	144	11.27%

† $p < 0.10$

Women with AFR ≤15 have more total pregnancies-for-age than women with later AFRs (Table 9a and 9b; $F(2,1315) = 46.990$ $p < 0.001$). AFR was not associated with number of miscarriages (Controlling for age, age^2 and number of pregnancies ($F(2,1315) = 1.777$, $p = 0.170$)). However, AFR ≤ 15 women have more infant deaths than AFR ≥ 20 women (Table 9b; $F(2,1315) = 4.636$, $p = 0.010$). Tsimane women with AFR ≤15 have more pregnancies and live births than other women, equivalent number of miscarriages controlling for their higher fertility, and likely greater reproductive success than women with later AFR. The higher infant mortality of women with AFR ≤15, compared to women with AFR ≥20, is unlikely to bring their reproductive success (number of children surviving to >15 years) below that of women with AFR ≥20 given the higher fertility of AFR ≤15 women.

Table 9a. Descriptive table of the reproductive outcomes of all births.

AFR (years)	Women	Pregnancies	Miscarriages		Live Births	Sex (0=daughter, 1=son)		Infant Deaths ≤ 1 year	
	n	*n*	*n*	Rate	*n*	Sons	Sex Ratio	*n*	Rate
12-15	167	888	22	2.48%	866	487	0.52	69	7.97%
16-19	778	3361	61	1.81%	3300	1937	0.51	220	6.67%
20-25	373	1530	20	1.31%	1510	851	0.52	60	3.97%
All (12-25)	1318	5779	103	1.78%	5676	3275	0.52	349	6.15%

Table 9b. Studentized residuals of the reproductive outcomes of all births. Pregnancy is controlled for age and age^2; miscarriages for age, age^2 and number of pregnancies; infant deaths for age, age^2 and number of live births.

AFR (years)	Women	Pregnancies		Miscarriages		Infant Deaths ≤ 1 year	
	n	*Mean ±SD*	*Mean difference*	*Mean ±SD*	*Mean difference*	*Mean ±SD*	*Mean difference*
12-15	167	0.48 ±1.17	-	0.10 ±1.53	-	0.11 ±1.36	-
16-19	778	0.07 ±0.94	0.41 ±0.08***	0.01 ±0.91	0.09 ±0.09	0.04 ±0.10	0.07 ±0.09
20-25	373	-0.35 ±0.92	0.83 ±0.09***	-0.07 ±0.86	0.17 ±0.09	-0.14 ±0.78	0.25 ±0.09*
All (12-25)	1318	0.00 ±1.00	-	0.00 ±1.00	-	0.00 ±1.00	-

**p* < 0.05, ****p* < 0.001

Looking at a subset of Tsimane women, with the year and outcome of all pregnancies and births known, suggests Tsimane women who reproduce at ≤15 years have higher infant mortality rates than AFR 16-19 women, and higher child mortality rates than AFR 16-19 or AFR ≥ 20 women (Table 10 and Table 11). However, it is not sufficient to bring the reproductive success of women with AFR ≤15 below that of women with later AFR (Table 11): number of children predicted to survive to ≥15 years for AFR ≤15 years = 8.92, AFR 16-19 years = 8.38 and AFR ≥20 years = 6.62.

Table 10. Infant mortality rates (death at ≤ 1 year) of Tsimane women born 1943-1990 by mother's age at infant's birth. Found using retrospective reproductive histories and THLHP census data. Women are separated by AFR. Number of births at risk of infant death by AFR: ≤ 15 = 331, 16-19 = 1350, 20-25 = 463.

Mother's Age at Infant's Birth (years)	**Infant Deaths at ≤ 1 years per 1000 Births**			
	AFR ≤ 15	**AFR 16 – 19**	**AFR 20 - 25**	**All Women**
10 - 14	83.33	NA	NA	83.33
15 - 19	164.95	95.24	NA	109.47
20 - 24	98.36	120.99	150.60	126.58
25 - 29	80.00	106.72	135.71	112.87
30 - 34	159.09	92.59	102.27	105.44
35 - 39	76.92	127.27	106.38	112.24
40 - 44	166.67	78.95	90.91	107.14
45 - 50	500.00	0.00	NA	250.00
All Ages	129.91	106.67	129.59	115.21
Predicted Total Infant Deaths	***1.44***	***1.05***	***0.96***	***1.09***
Predicted Total Infants Surviving to ≥ 1 Year	***9.67***	***8.86***	***7.04***	***8.46***

Table 11. Child mortality rates (death at ≤ 15 years) of Tsimane women born 1943-1990 by mother's age at child's birth. Found using retrospective reproductive histories and THLHP census data. Women are separated by AFR. Number of births at risk of child death by AFR: ≤ 15 = 331, 16-19 = 1350, ≥ 20 = 463.

Mother's Age at Infant's Birth (years)	Child Deaths at ≤ 15 years per 1000 Births			
	AFR ≤ 15	AFR 16 - 19	AFR 20 - 25	All Women
10 - 14	83.33	NA	NA	83.33
15 - 19	257.73	145.50	NA	168.42
20 - 24	147.54	172.84	228.92	185.13
25 - 29	100.00	150.20	164.29	148.98
30 - 34	272.73	129.63	125.00	149.66
35 - 39	179.49	172.73	106.38	158.16
40 - 44	166.67	131.58	136.36	142.86
45 - 50	500.00	0.00	NA	250.00
All Ages	196.37	154.07	172.79	164.65
Predicted Total Child Deaths	***2.19***	***1.53***	***1.38***	***1.54***
Predicted Total Children Surviving to > 15 Year	***8.92***	***8.38***	***6.62***	***8.01***

The greater reproductive success of AFR ≤15 women is further supported by the reproductive histories of women aged ≥45 years – women who have completed their reproduction (Table 5). Among Tsimane women aged ≥ 45 years, AFR ≤15 women had on average: more infant deaths than AFR ≥20 women ($F(2,240) = 4.607$, $p = 0.011$); trended toward having more children die between 1-5 years old than AFR ≥20 women ($F(2,240) = 2.650$, $p = 0.073$); and had more children die between 6 to 15 years old than AFR ≥20 women ($F(2,240) = 5.253$, $p = 0.006$), and trended toward more children dying between 6-15 years than AFR 16-19. Despite lower infant and child survival, AFR ≤15 women have high reproductive success. Women with AFR ≤15 had equivalent reproductive success to AFR 16-19 women, but almost double that of AFR ≥20 women (Table 5; $F(2,240) = 18.787$, $p < 0.001$).

To summarize, AFR ≤15 women may be more likely to miscarry their first pregnancy than women with later AFRs, but subsequent pregnancies do not have a higher risk of miscarriage. Women who reproduce at ≤15 years may have higher risk of infant and child death throughout their lives than women with later AFR. **Hypothesis 3 is not supported. Despite AFR ≤15 women's potentially higher risk of miscarrying their first pregnancy and higher risk of later born infant and child deaths, their reproductive success does not fall below that of AFR 16-19 women and remains well above that of AFR ≥ 20 women.**

Looking among women aged ≥45 years shows that adult height has long-term effects on women's reproductive success. Age at first reproduction is negatively associated with reproductive success (b^* = -0.49, $t(241)$ = 15.71, p <0.001) and explains 24% of the variation in reproductive success (R^2 = .24, $F(1, 241)$ = 77.32, p < .001): Tsimane women with younger AFR have greater reproductive success than women with later AFR. However, controlling for AFR, reproductive success trends toward a positive association with adult height (b^* = 0.11, $t(199)$ = 1.66, p = 0.09): **women with younger AFR who are relatively taller likely have the greatest reproductive success.**

4. Childhood Condition and AFR (H4)

Tsimane women who experience early growth (tall-for-age between 10-12 years) experience earlier ages at menarche and AFR (Figure 4). However, among women with known childhood and early adolescent heights early menarche is not associated with earlier AFR or adult height (Figure 4); and among women with known adult height age at menarche was equivalent across AFR groups (Table1; $F(2,360)$ = 1.622 p = 0.199). Women who reproduce at ≤15 years are tall-for-age before birth, but short-for-age post-reproduction – supporting compromised growth during mid-to-late adolescence in early reproducers (Table 12; Figure 2 and 6). Furthermore, AFR ≤ 15 women have greater body mass indices (BMI) before primigravidity than AFR ≥ 16 women (Table 13; Figure 7), but equivalent BMI in adulthood (Table 2). **Hypothesis 4 is supported. Among Tsimane women, greater pre-reproductive height and BMI during late childhood and early adolescence – indicative of better childhood and early adolescence health and nutrition -- are associated with earlier menarche and AFR, and greater adult height.**

Table 12: Mean heights of Tsimane women from 10 to 20 years. We compare across two groups: (1) women who give birth at ≤15 years (≤15); and (2) women who gave birth at ≥16 years (≥16). Pregnancy or being parous do not exclude a woman from the below. Significant differences within an age group by AFR are indicated in bold. The three age groups with significant differences in year of birth are indicated with * on their mean year of birth.

Age at Height	AFR	*n*	Year of Birth Mean	Height (cm) Mean	t	*df*	Mean Difference in Height (cm)
10	**≤ 15**	19	1994.63 ±1.38	133.13 ±6.47	2.59	27	6.53*
	≥ 16	10	1993.10 ±0.57	126.6 ±6.42			
11	**≤ 15**	30	1993.67 ±1.81	136.74 ±5.66	3.45	50	6.28**
	≥ 16	22	1992.91 ±1.15	130.46 ±7.49			
12	**≤ 15**	34	1993.09 ±1.58	143.27 ±4.36	1.81	64	2.33†
	≥ 16	32	1991.97 ±1.49	140.94 ±6.02			
13	**≤ 15**	30	1993.20 ±2.14	145.67 ±4.39	0.72	75	1.01
	≥ 16	42	1992.00 ±1.53	145.09 ±4.91			
14	**≤ 15**	34	1993.03* ±1.82	148.76 ±3.41	2.23	94	2.04*
	≥ 16	64	1991.16 ±1.88	146.72 ±5.63			
15	**≤ 15**	42	1992.81 ±1.81	148.67 ±3.12	-2.82	113	-2.17**
	≥ 16	67	1991.00 ±2.30	149.84 ±3.87			
16	**≤ 15**	46	1992.35 ±1.80	149.65 ±3.74	-1.22	144	-0.89
	≥ 16	100	1990.13 ±2.20	150.54 ±4.24			
17	**≤ 15**	31	1990.74 ±2.28	149.44 ±4.57	-0.86	135	-0.79
	≥ 16	106	1989.53 ±2.60	150.23 ±4.49			
18	**≤ 15**	23	1990.61 ±1.95	150.80 ±3.41	0.43	146	0.4
	≥ 16	125	1988.97 ±2.52	150.40 ±4.13			
19	**≤ 15**	17	1988.41 ±2.40	148.61 ±4.66	-2.3	161	-2.34*
	≥ 16	146	1987.91 ±2.42	150.95 ±3.89			
20	**≤ 15**	25	1986.60 ±3.00	148.52 ±5.19	-2.87	201	-2.72**
	≥ 16	178	1987.30 ±2.46	151.23 ±4.31			

†$p < 0.10$, *$p < 0.05$, **$p < 0.01$

Table 13: Mean BMI of Tsimane women from 10 to 14 years by AFR with women repeated between age groups but not within (n = 116, obs. = 284). Significant differences within an age group by AFR are indicated in bold. Only women aged 10 to 14 and not pregnant are shown. All women who had given birth were removed. By age 15 all AFR ≤15 women had given birth or gave birth that year hence only 10 to 14 years are considered here. Postpartum women are removed as pregnancy and postpartum are new life stages making a direct comparison of BMI between early AFR and late AFR that includes postpartum early AFR women dubious.

Age at BMI	AFR	*n*	BMI (kg/m^2) Mean ±SD	t	*df*	Mean Difference in BMI (kg/m^2)
10	**≤ 15**	19	17.24 ±2.04	1.04	27	0.71
	≥ 16	10	16.5 ±1.27			
11	**≤ 15**	29	18.31 ±2.12	2.32	49	1.41*
	≥ 16	22	16.9 ±2.20			
12	**≤ 15**	31	20.26 ±2.37	2.87	61	1.69**
	≥ 16	32	18.57 ±2.30			
13	**≤ 15**	26	20.52 ±1.98	2.56	65	1.43*
	≥ 16	41	19.09 ±2.37			
14	**≤ 15**	11	21.74 ±1.92	1.19	72	1.05
	≥ 16	63	20.69 ±2.81			

*$p < 0.05$, **$p < 0.01$

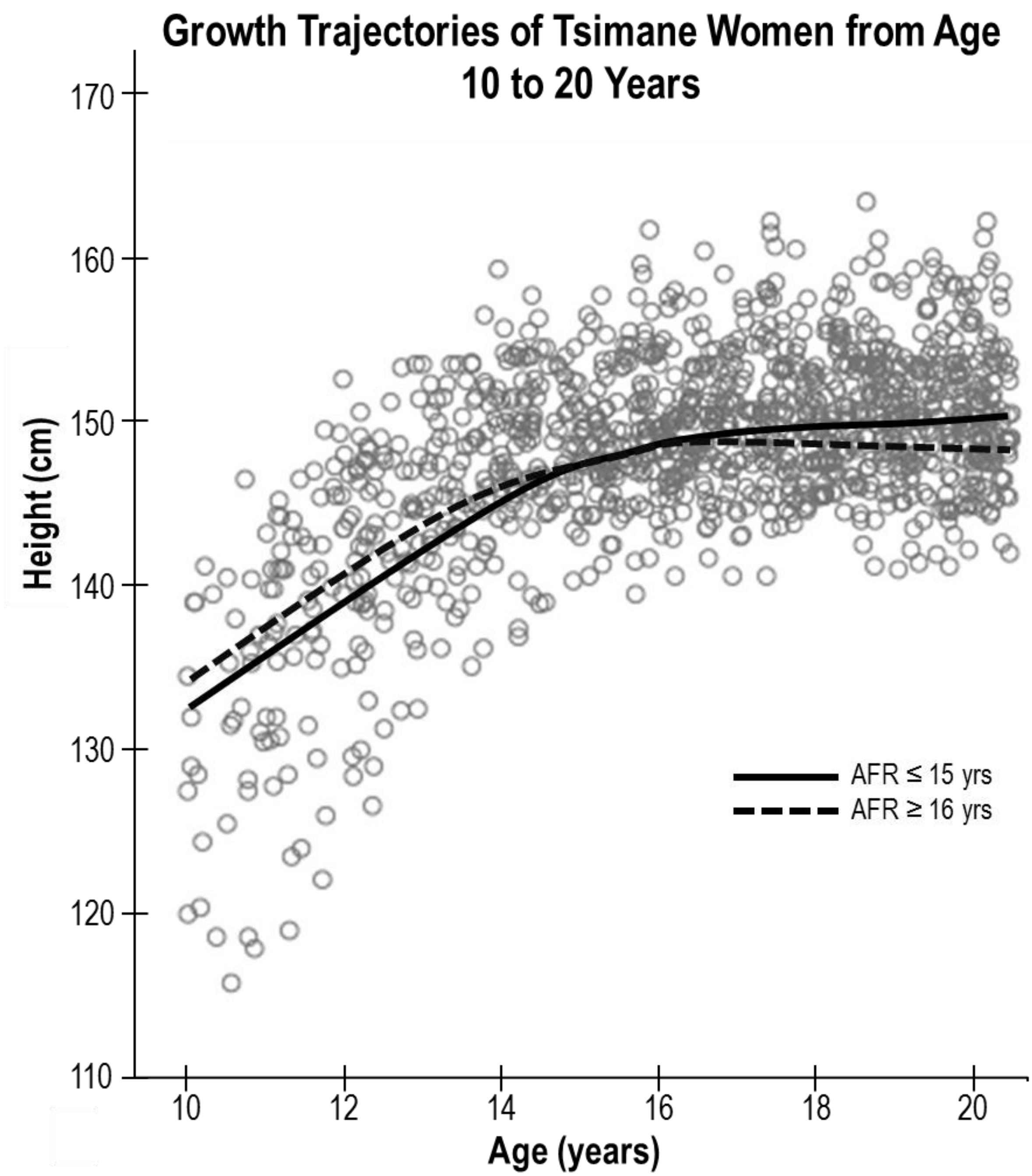


Figure 6. Height trajectories of Tsimane women from late juvenile through adolescence (*n* = 444, observations = 1223). There are two distinct growth trajectories: (1) precocious investment in growth with reduced to no investment after ~15 years, as indicated by the dashed? line (AFR ≤ 15 years, *n* = 111, obs. = 331); and (2) slow prolonged invest in growth through to ~17 years, as indicated by the solid? line (AFR ≥ 16 years, *n* = 333, obs. = 892). The lines are Loess Curves fit to 80% of data points.

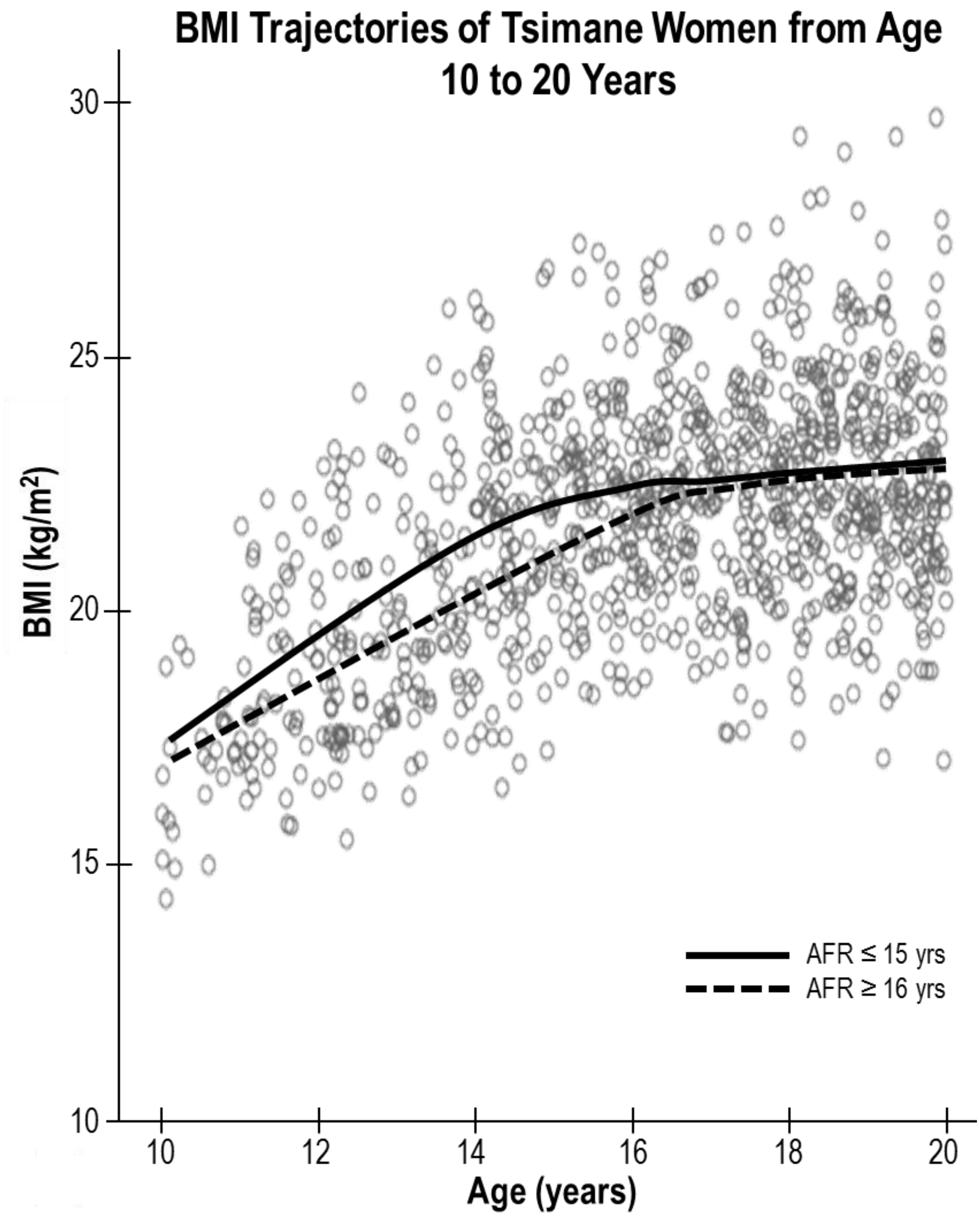


Figure 7. Change in BMI of Tsimane women from late juvenile through adolescence (*n* = 444, observations = 1223). There are two distinct weight gain trajectories: (1) precocious investment in weight gain, as indicated by the solid black line (AFR ≤ 15 years, *n* = 111, obs. = 331); and (2) slower weight gain through to ~17 years, as indicated by the dashed black line (AFR ≥ 16 years, *n* = 333, obs. = 892). The lines are Loess Curves fit to 80% of data points.

D. Discussion

This article presents evidence that adolescent reproduction limits, but does not stop, maternal growth (H1); and that adolescent reproduction may be optimal among a natural fertility population with relatively high mortality risk (H2 and H3). Reproduction at ≤15 years being sub-optimal compared to later AFR was not supported (H3). Instead, extreme precocious reproduction (reproduction at ≤15 years) appears to be a flexible response among Tsimane girls, who grow rapidly in childhood in a resource limited population, where extrinsic mortality risk is comparatively high. Variation in AFR, and related adult height, are dependent on childhood condition (H4) and assumedly access to sexual relations.

The Tsimane, like many indigenous groups, are a high fertility population (TFR = 9.55) in which adolescent reproduction is the norm – 13% of women are mothers by age 15 and 59% by age 19, and 35% of these adolescent mothers are multiparous by age 20. Among the Tsimane, motivation to delay reproduction until ≥ 20 years is low. Women's status and sociopolitical power remain tied to their somatic wealth and reproductive history; and accessible and culturally accepted career options beyond motherhood are rare (McAllister, Gurven, Kaplan, & Stieglitz, 2012; Veile, Martin, McAllister, & Gurven, 2014). Motivation to reduce fertility is also low. Large families increase the parents' sociopolitical power, and provide valuable labor and care as parents age. This allows us to shed light on the benefits and costs of adolescent reproduction from a biological and evolutionary perspective, as measures of reproductive success are less impinged by the socioeconomic and political changes seen in most populations. The fact that among the relatively environmentally homogenous Tsimane women, and even among sister-dyads, variation in AFR are observed adds additional understanding to human phenotypic plasticity, and the benefits and costs of adolescent reproduction, including how maternal growth is affected.

1. AFR and Maternal Growth (H1)

Natural selection should favor women that complete their skeletal growth and accruement of necessary energy stores before they are fecund (Ellison, 2001; Kramer & Lancaster, 2010; Jane B Lancaster, 1986; Lassek & Gaulin, 2007). Conversely, among Tsimane women, fecundity and motherhood well before cessation of skeletal growth, and continued skeletal growth during reproduction, are common. Growth in stature during and after adolescent pregnancy has been shown among adolescent mothers in England, the United States and India (Rah et al., 2008; Schnall et al., 1994; Stevens-Simon & McAnarney, 1993; Sukanich et al., 1986).

Despite concurrent somatic and reproductive investment there is a negative relationship between AFR and adult height. Extreme precocious reproducers, AFR ≤ 15 years, are more than a centimeter shorter than their later reproducing peers in adulthood. It is likely reproduction, and not predisposed growth trajectories with earlier cessation of growth, that limits AFR ≤15 women's heights. Comparing within sister dyads, women who began their reproductive lives at ≤15 years are on average more than two centimeters shorter than their AFR ≥16 years sisters. Furthermore, among Tsimane women on similar growth trajectories during childhood and early adolescent AFR ≤15 women are shorter than AFR ≥16 women.

Smaller adult stature, due to compromised childhood and adolescent growth, is associated with lower cognitive development, poorer adult health outcomes, and lower adult economic and sociopolitical success (Dewey & Begum, 2011; Sear, 2010; Walker et al., 2007). However, among the Tsimane, shorter adults do not experience greater health, economic or sociopolitical penalties than their taller same sex peers (Godoy et al., 2010).

In industrialized countries, women shorter than 152cm are more likely to have small pelvises and consequently are at higher risk for dystocia, preterm labor and intrauterine growth restriction, and associated lower infant birth weight and infant survival (Brown, 2010). The average Tsimane women has a comparably short height (mean height = 151 ±4.52cm). However, their infants are well above the World Health Organization definition of low birth weight (<2,500 grams) and within the 50th percentile for length: the mean weight and height of ten Tsimane neonates, taken within a two-week postnatal period, was 3,200 grams and 49.7cm respectively (Martin, in prep). Tsimane women are likely at high risk for the poor pregnancy outcomes associated with having a small pelvis. Women that reproduce at ≤15 years should have smaller pelvises and birth canals during this first pregnancy than women with later AFR. However, among the Tsimane first born children of AFR ≤15 women are no more likely to die during infancy than the first-born children of women with later AFRs. Women with AFR ≤15 years may attain larger adult pelvic and birth canal size in early adolescence than those with AFR ≥16 years (as suggested by their greater height between 10 to 12 years), thereby lowering their obstetric risk. Growth of the pelvis and birth canal are known to continue beyond the asymptote for statural increase (Moerman, 1982), and as post-partum growth in stature occurs among Tsimane women we can assume AFR <15 women have larger pelvises and birth canals for their later pregnancies. However, AFR trends toward a negative association with lifetime infant mortality and AFR ≤15 women have higher infant mortality rates than AFR ≥20 women. The difference in pelvis size by AFR and height among Tsimane women, and how this affects their pregnancy outcomes requires further study.

2. AFR and Fertility (H2)

Tsimane women with younger AFR have more pregnancies and live births over their lifetimes than women with later AFR. The greater fertility of AFR ≤15 women is due to their longer reproductive lives rather than shorter interbirth intervals: AFR ≤15 women have earlier onset and later cessation of reproduction. The earlier onset of reproduction in AFR ≤15 women is likely due to earlier and greater fecundity, and earlier access to sex -- AFR ≤15 women marry earlier than AFR ≥ 16 women. These young brides were more likely to divorce and remarry than older first time brides. Father absence and disinvestment, and presence of a step-father are assumed to increase infant and child mortality. However, among the Tsimane the effect is minimal and likely limited through provisioning and care by maternal kin (Winking, Gurven, & Kaplan, 2011); and mixed support for father absence having negative effects on child wellbeing has been found among other indigenous groups (Hagen, Hames, Craig, Lauer, & Price, 2001; Hurtado & Hill, 1992; Sear, Mace, & McGregor, 2000; Sear & Mace, 2008)

Tsimane women that reproduce by 15 years on average have greater BMI pre-reproduction than women with later AFR. Greater adolescent BMI, but below obese levels, is associated with earlier fecundity and likely a more adult appearance depending on fat distribution (Ellison, 2001). Furthermore, adolescent BMI has a U-shaped relationship with fertility (Figure 1 in Jokela et al., 2007). Given the adolescent BMI range observed in our study (mean = 20.29 ±3.40) we expect a positive association between adolescent BMI and fertility. Women with better childhood condition, as suggested by their greater adolescent BMI, enter adolescence with long-lasting reproductive advantages starting with earlier fecundity and achievement of adult appearance needed to attract sexual partners, and ending with a later cessation of fecundity, and greater fertility. The later age at last birth may suggest that AFR ≤15 women maintain a better maternal condition throughout their lives, or that childhood adolescent condition influences women's age at menopause and degree of pre-menopausal subfecundity.

3. AFR and Reproductive Success (H3)

Women that reproduce by 15 years trend toward higher rates of miscarriage of first pregnancy -- expected given incomplete maternal skeletal development and greater fetal-maternal gestational competition for resources (Gibbs et al., 2012; Schnall et al., 1994; Zabin & Kiragu, 1998)-- and generally higher infant and child mortality rates. However, AFR ≤15 women are twice as likely to be multiparous by age 20 and, on average, have one to three more surviving children by cessation of reproduction than AFR 16-19 and AFR 20-25 women respectively. The longer reproductive lives of AFR ≤15 women allows for greater fertility which compensates for their higher number of failed pregnancies. AFR ≤15 women have greater reproductive success than women with later AFRs.

The early adolescent growth and BMI of AFR ≤15 women may buffer them against the costs of precocious reproduction such that their risk of miscarriage, and infant and child mortality is not appreciably higher than that of women with later AFR. In a high mortality environment where large kinships provide valuable sociopolitical and economic support, and children provide valuable labor, sibling care and parental care in old age, high fertility is key.

Women that reproduce by age 15 likely have mothers and grandmothers who are younger and healthier and, thus, better able to assist with first born care and care of subsequent children until first born children themselves become helpers. Considering Tsimane women commonly reside matrilocally for several years post-marriage, when at least the first birth and possibly second birth occur, this could be invaluable help and greatly reduce the cost of extreme precocious reproduction. Furthermore, many of the negative outcomes of precocious reproduction are linked to paternal absence (D. Coall et al., 2012; Hewlett, 2010); this is not a common issue among Tsimane women as most are married when they reproduce.

Among environmentally stressed populations shorter height is associated with poorer pregnancy outcomes, and smaller women have lower reproductive success (Pollet & Nettle, 2008; Sear, 2010); for example, Sear (2004) found, among four rural Gambian villages, that taller women have later AFR but lower infant mortality than shorter women, and consequently higher reproductive success. However, among the Tsimane, AFR ≤15 years women have greater reproductive success than women with later AFR. The reproductive success of AFR ≤15 years women, despite their shorter stature and higher risk of failed pregnancies, may be related to Tsimane women rarely experiencing prolonged resource stress due to strong food sharing networks and their comparatively resource rich environment. Tsimane women's relatively stable and sufficient resource supply may in fact support successful adolescent reproduction. It has been suggested, using ewes as a model species, that both over-nourishment and undernourishment of adolescent mothers may reduce placental and fetal growth and lead to poor pregnancy outcomes (Wallace et al., 2006). However, controlling for AFR, taller women have greater reproductive success, suggesting long-term benefits to continued growth during pregnancy and lactation; and that taller AFR ≤15 women have the greatest reproductive success.

4. Childhood Condition and AFR

The Tsimane mothers in this study grew up in a harsh environment. Infant mortality was high (1950-1989 Tsimane infant mortality was 153 deaths per 1000 live births, declining to 126/1000 from 1990-2002 (Gurven et al., 2007)), life expectancy low (from birth life expectancy was 44.2 for males and 42.8 for females in 1950-1989, increasing to 54.3 and 54.0 respectively from 1990-2002 (Gurven et al., 2007)), and infectious and parasitic disease the most common causes of death (Gurven, 2012; Gurven et al., 2007). This should encourage a relatively fast life history strategy of early maturity and cessation of growth, early reproduction, and a preference for high fertility (enabled by earlier reproduction). Foster et al (2005) found stunting to be common (43% of girls had low height-for-age compared to US and European children) but wasting to be rare (only 6% of these girls had low weight-for-height) in Tsimane girls aged ≤9 years. This suggests that resource access during these women's childhoods was likely stressed but sufficient, such that, acute malnutrition was rare despite energetic limitations and high pathogen load. All Tsimane women likely tend toward a fast life history strategy, due to their high extrinsic mortality risk and short life expectancy; however, some women may be better able to accelerate the onset of their reproduction while limiting potential costs.

Among the Tsimane, women who reproduce extremely early, at ≤15 years, usually had better childhood condition than their peers, as evidenced by their greater height-for-age and BMI before they reproduce, and earlier age at menarche (note age at menarche is not associated with AFR). However, AFR ≤15 years women, despite faster childhood growth, are not following a markedly faster life history strategy, with earlier attainment of adult size and cessation of growth, than AFR ≥16 years women. First, among the Tsimane, extreme precocious reproducers have not achieved adult size or the asymptote of their growth trajectory, pre-reproduction. Second, AFR ≤15 years women have not stopped investment in their skeletal growth -- 75% of AFR ≤15 years women had post-partum growth in height. Third, it is reproducing early that limits women's growth -- women with greater height-for-age and BMI in childhood and early adolescence, who do not reproduce at ≤15 years, continue their somatic investment during adolescence unimpeded by competing reproductive demands and are relatively tall as adults. Fourth, comparing sister dyads, with assumedly similar childhood environments and genetic backgrounds, the height deficit experienced by the AFR ≤15 years sister supports that it is reproducing in early adolescence -- normally an important period of growth and development, including the adolescent growth spurt -- that limits adult height and not a faster life history strategy with earlier cessation of growth. However, childhood condition affects women's ability to reproduce early and consequently sets them on a different life history trajectory with an earlier AFR, a possibly later age at last birth, and given relatively low variation in interbirth intervals, and infant and child mortality by AFR greater reproductive success. Women on slower growth trajectories may be fecund at ≤15 years (age at menarche was equivalent across AFR groupings and variation in length of sub-fecundity post-menarche among AFR groups is unknown); however, they are unlikely to attract a sexual partner until they have achieved a more adult appearance. If a sexual partner is secured, and assuming their slower growth is due to continuing poor condition, early fetal loss is likely.

E. Conclusion

Women in harsh environments cannot risk delaying reproduction but there are lifelong costs to early cessation of growth, including underdeveloped pelvis and increased risk of obstetric complications and, thus, higher risk of infant mortality and maternal mortality, morbidity and disability. Being able to invest in reproduction early, despite the relatively higher risk of poor pregnancy outcomes, provides a longer reproductive lifespan and potential greater reproductive success. Being able to continue somatic investment during early pregnancy and lactation may reduce or eliminate the long-term negative consequences of precocious reproduction. Therefore, in a population with short life-expectancies and high extrinsic mortality, extreme precocious reproduction may be an important strategy and the long-term costs reduced due to continued maternal somatic investment. Among Tsimane women, better childhood condition allows reproduction at ≤15 years and may cushion against the full negative consequences of extreme precocious reproduction and shorter adult stature seen in other populations. However, the first-born child must pay a cost as his/her resource access is restricted by his/her mother's competing somatic investments (Scholl et al., 1994).

We shed light here on human phenotypic plasticity; providing evidence of differences in developmental reaction norms due to variation in health, resource access and opportunity among women within a single population. We also broaden perspectives on the costs and benefits of adolescent reproduction, concurrent reproduction and growth, and show within population variation in life history events historically under strong selective pressure.

Adolescent reproduction is considered a problem, and millions are spent on programs to reduce adolescent reproduction rates each year. However, from a life history perspective adolescent reproduction may often be viewed as an appropriate response to harsh environments. Furthermore, considering the high pathogen loads and low life expectancy throughout our evolutionary past, and our resource limitations, fast life history strategies with young AFR were likely the norm. Today, adolescent reproduction is a problem in part due to cultural sanctions and the extended human capital investments required for socioeconomic success. Policy makers would benefit from using life history theory to understand what drives young AFR and, thus, how best to help at risk girls. Several researchers have begun advocating for considering evolutionary theory, and specifically life history theory, in policies related to adolescent reproduction (D. Coall et al., 2012; Ellis et al., 2012b; Geronimus, 1996; Johns, Dickins, & Clegg, 2011; Kramer, 2008; Low et al., 2013).

V. Conclusion and Future Directions

A. Family planning in a "natural fertility" population

The Tsimane are Bolivian forager-horticulturalists at the cusp of a fertility transition and a rapidly increasing reliance on the market economy. Mortality has been declining since the 1990s (Gurven, 2012a; Gurven et al., 2007; Kaplan et al., 2015), but fertility remains high (total fertility rate = 9.1) and may increase — age at first birth is declining (Kaplan et al., 2015), while uptake of contraceptives remains low (Gurven, Costa, et al., 2016). The Tsimane have been gradually integrating into the local market economy since the 1970s when the New Tribe's Mission instigated the building of schools in many Tsimane communities, the logging and cattle industries (sources of mostly male employment) took off, and the nearby town of San Borja expanded. Even Tsimane resistant to market integration are increasingly forced to partake in selling produce and handmade items to purchase medicines, clothes and food, for which at least a basic education and Spanish fluency are advantageous. There is also increasing interest in earning income, which positively associates with social status (Gurven, Jaeggi, von Rueden, Hooper, & Kaplan, 2015), and in owning modern luxury items, such as televisions, mobile phones and mopeds. Cattle ranches and logging companies are also increasingly encroaching on Tsimane land, which coupled with the Tsimane's high population growth rate of >3% is encouraging deforestation and over-use of farmlands — the Tsimane's subsistence life style is being limited from multiple angles.

Given this transformation in economy and lifestyle, the Tsimane offer an excellent case study of how changes in mortality risk (Chapter II), and in how embodied capital is accrued (Chapter III), affect reproductive preferences and behaviors. Current research based on demographic transition theory utilizes historical data sets from developed countries, and observations of large urban (and sometimes rural) populations in developing countries. This work to date has not developed a detailed understanding of fertility change, including the underlying psychological mechanisms, that coupled with physiological controls, influence the timing of human reproduction. Evolutionary demographers, and proponents of life-history theory, have long called for more fine-tuned studies in populations with subsistence-based economies and a focus on the psychological mechanisms that influence human reproduction, to better understand what specific ecological, social and economic cues encourage fertility decline, and the interplay and cultural specificity of these relationships (Kaplan, 1996; Kaplan et al., 2015; McAllister et al., 2016).

Specific benefits of this better understanding may be the elucidation of why, in many low- and middle- income countries, fertility transitions have stalled at above replacement fertility levels. This coupled with these countries low mortality rates means population growth remains high, and ecologically and economically unsustainable. Conversely, a better understanding of what encourages fertility decline may also help elucidate how to encourage higher fertility: Fertility has dropped to below replacement levels in many high-income countries, bringing with it the numerous economic problems of an aging population, and a growing interest in encouraging reproduction in these populations (G. Pepper, McAllister, & Sear, 2016).

How physiology affects the timing of human reproduction is relatively well established, e.g. women’s nutritional status has an inverted U-shaped relationship with fecundity (Bongaarts, 1980; Gaskins, Rich-Edwards, Missmer, Rosner, & Chavarro, 2015), and time to resumption of ovulation post-partum is positively associated with duration and intensity of breastfeeding (Bongaarts & Potter, 1983; Ellison, 2001; Valeggia & Ellison, 2009). It is also relatively well known how the timing of women's first birth, and subsequent births, is influenced by cultural norms (e.g. marriage practices, post-partum abstinence beliefs, and acceptance of contraceptive use) and opportunity (e.g. finding and retaining a suitable mate). However, variation in physiology, culture and opportunity among women does not explain all variation in reproductive timing and fertility. An additional component that may explain variation in reproductive timing and fertility among women, is how environmental cues are perceived, processed, and translated into reproductive preferences and behaviors by underlying psychological mechanisms (McAllister et al, 2016).

Psychological mechanisms that enable individuals to accurately perceive and predict environmental risks, and adjust their behaviour accordingly, whether consciously or sub-consciously, should be favoured by natural selection. For example, individuals that accurately infer their life expectancy, from observations of adult mortality risk in their local population, will be better able to adjust the timing of their first birth and subsequent births, and trade-offs between investments in embodied capital versus reproduction, compared to individuals that are unable to predict their life expectancy. Previous studies suggest that perceptions of local environmental factors, e.g. life expectancy and socioeconomic status, influence individual life-history strategies (Copping & Campbell, 2015; Johns, 2011; Nettle, Coyne, & Colléony, 2012). However, few attempts have been made to expose the underlying psychological mechanisms, or address how accurately people perceive environmental risk, despite their existence and efficacy being implicitly assumed by many life-history studies (see McAllister et al, 2016 for a review). There is some evidence that local mortality and morbidity risk may be accurately perceived, while adult sex ratios and crime rates are not (Gilbert, Uggla, &

Mace, 2016). However, as with many life-history studies, this work is within a Western population where mortality risk is relatively low and ability to control health is greater – research in non-Western populations where mortality risk is a more prevalent issue is needed. Throughout this dissertation I have begun to expose these psychological mechanisms, explore what specific environmental factors they may be attuned to, and assess where possible how accurately environmental risk is perceived. I do this in a population more reminiscent of our evolutionary past and possibly a clearer window to how environmental cues influence the pace of individual life histories.

It is also important to acknowledge that in some instances high fertility, and behaviors that enable high fertility, such as younger ages of first birth (Chapter IV), may optimize their socioeconomic or reproductive success given an individual's ecological, social, cultural and economic circumstance. For example, teenage pregnancy appears detrimental to women and children's health and socioeconomic success when comparing populations where it is prevalent to populations where it is rare. However, when examined on a more individualistic platform the advantages to women and their children of teenage pregnancy become apparent, helping to explain why this reproductive behavior exists and persists despite international and local education and health policies aimed at stopping it. For instance, a growing number of studies suggesting that teenage pregnancy is an optimal strategy under conditions of resource stress, psychological stress, paternal absence, and/or high extrinsic mortality (Chisholm et al., 1993, 2005; Ellis, 2004; Ellis et al., 2012a; Geronimus, 1996; Kramer & Lancaster, 2010; Migliano et al., 2007; R. Walker et al., 2006; Wilson & Daly, 1997). In this dissertation, I examine among Tsimane women: (1) how experienced and perceived mortality risk may influence experienced and preferred life history pace; (2) how changes in how embodied capital is accrued may influence reproductive preferences for children; and (3) life-history trade-offs between growth and reproduction, and whether teenage reproduction is an optimal strategy given the cultural and socioeconomic environment of the Tsimane. Throughout this dissertation I explore possible psychological mechanisms influencing human reproduction by examining how women's perceptions of their local environment may influence their reproductive preferences. The results suggest that the relationships among factors influencing women's reproductive preferences for themselves and their children, and their reproductive behaviours may not follow simplistic interpretations of life-history theory.

B. Main findings

1. Mortality risk predicts preferred and actual life history pace, but not as expected.

Life history theory and cross-cultural evidence suggest a negative association between extrinsic mortality risk and life history pace. In Chapter II I presented two studies that explored the relationship between mortality risk and life history pace. In Study I, I explored how women's experiences and perceptions of mortality, and perceptions of morbidity, influence their preferred age of first birth for their children, whether they wanted their children to have few or many children, and their preferred interbirth interval for themselves.

I found that Tsimane women's perceptions of their mortality risk may be inaccurate: Women living closest to town, where mortality risk was lower, were more likely to perceive infants and children in their community to often die rather than sometimes die, compared to women living further from town, where mortality risk was higher. However, this may be due to perceptions tracking recent events rather than long-term trends, as in the near town community, several infants and children from a prominent family had recently died. How accurately age specific mortality risk is perceived, and how perceptions are affected by recent events, requires further testing among the Tsimane.

Overall my results were mixed (see Chapter II Table 20 for a summation of the results) disputing simplistic assumptions from life-history theory that high mortality risk is associated with a fast life history pace. For example, women who in adulthood experienced high infant mortality and perceived child mortality risk to be high favoured slower life history paces for their daughters. However, women who in childhood had experienced high infant mortality favoured faster life history paces for their daughters. This supports life history strategies being formed in childhood but remaining somewhat flexible in adulthood allowing for optimal behaviour in a possibly fluctuating environment.

I also found that Tsimane women have distinct reproductive preferences for sons versus daughters that are influenced by divergent factors. For example, for sons, women who perceived child mortality risk to be high favoured older ages of first birth, but preferred their sons to have many children. Given the different reproductive potentials of sons and daughters, and the greater valuation of sons compared to daughters in Tsimane society, this is unsurprising. Encouraging a son to delay reproduction allows for more time for a son to help support his natal family, and accrue the skills and resources needed to be a successful adult. Once married, and assuming a son is a good provider, the burden of a son's high fertility is carried by an un-related daughter-in-law who may be seen as replaceable. Whether women's reproductive preferences for their children are influenced by their children's reproductive potential may be better assessed by investigating if women's perceived quality (e.g. ability to accrue resources) of their children, especially sons, is associated with their reproductive preferences for their children. For example, do women that perceive their sons to be high quality have larger preferred family sizes for their sons than women who perceive their sons to be low quality; and does this relationship hold when comparing among a woman's own sons (assuming within clutch variation in son quality)?

In Study II I explored how childhood exposure to infant mortality affected women's life history paces. I found that exposure to older sibling infant deaths predicted a slower life-history pace (e.g. older ages of first birth and lower parity-for-age), while exposure to younger sibling infant deaths predicted a faster life-history pace (e.g. younger ages of first birth).

The disparate effects of older and younger infant sibling deaths suggest different pathways through which mortality exposure may influence life history pace. Older sibling infant deaths are unobservable but may change the parenting environment: Parents that have experienced many infant deaths may invest more heavily in subsequent children (Störmer & Lummaa, 2014), partly to help ensure their survival, but also because earlier child deaths free up resources enabling greater investment in later born children. This greater parental investment strategy may encourage a slower life history pace in later born children. It remains to be tested, among the Tsimane, whether infant deaths affect parenting strategy, especially amount and type of investment in surviving children. If infant deaths do change parenting strategy or free up resources enabling greater investment in surviving children, it is interesting that this effect only encourages a slower life history pace in later born children. This may suggest that early childhood is a pivotal period for setting an individual's general life history pace, and that later changes in parents' investment strategies have minimal influence on life history pace. See Coall et al (2016) for a review of the importance of childhood environment for setting an individual's life history pace.

2. More educated women do not prefer older ages of first birth for their children.

On average, when comparing across and within populations, more educated women start reproducing at older ages (Akman, 2002; Basu, 2002; Becker, 2009; John Bongaarts, 2003; Colleran et al., 2014; Grant, 2015; T. C. Martin & Juarez, 1995; Snopkowski et al., 2016; Tavares, 2008). Consequently providing education to women is a common focus of population policies aimed at reducing rates of teenage pregnancy. Several Tsimane villages have had schools since the 1970s, although a high school level education has only been available since the early 2000s. In Chapter III I explored whether more educated Tsimane women have older ages of first birth, or prefer older ages of first birth for their children. My results suggest that education has yet to directly encourage older ages of first birth among Tsimane women, or encourage older preferred ages of first birth for children. Furthermore, schools may be viewed by many parents as places that, as children are unsupervised by family members, enable earlier sexual debut, and increase the risk of early and unwanted pregnancies for daughters.

However, more educated women perceived higher returns to investments in educational capital; and women perceiving higher returns to education preferred older ages of first birth for their children. This suggests that perceiving there to be returns to investments in education, more so than education itself, may be key to encouraging delayed reproduction for both Tsimane women and men. This supports the economic theory of fertility decline.

Unfortunately, the Tsimane, like many indigenous groups, have low socioeconomic mobility, limited access to the labor market, and low value within it. The education available to the Tsimane is also of low quality with only the larger villages having high schools and post-secondary education being virtually inaccessible. Consequently, returns to educational investments are low for the Tsimane and are likely to remain so for the time being. Returns to educational investments for women are additionally limited by cultural cloistering of women, and low support for women living lives outside the mothering and homemaking role. Individuals are unlikely to forgo earlier reproduction in favour of investing in their education and joining the labor market when the opportunity costs of childbearing remain low, and their status within the family and their community remains linked to their reproduction.

3. Teenage pregnancy limits maternal growth but increases reproductive success

The assumption that adolescent reproduction – pregnancy and birth before the age of 20 – is detrimental to women's and their children's health, socioeconomic standing and mobility, or autonomy has been increasingly critiqued, and a growing body of research suggests that in some contexts it is advantageous (Chisholm et al., 1993, 2005; Ellis, 2004; Ellis et al., 2012a; Geronimus, 1996; Kramer & Lancaster, 2010; Migliano et al., 2007; R. Walker et al., 2006; Wilson & Daly, 1997). In Chapter IV I presented further support of this critique. Among Tsimane women, reproduction before the age of 16 years limits maternal skeletal growth, and these precocious reproducers have higher infant and child mortality rates. However, the higher lifetime fertility of precocious reproducers may outweigh these costs. In a society, like the Tsimane, where women's status is tied to their reproductive output and children provide valuable labor, help in old age and socio-political support, early and high reproductive effort is advantageous.

How teenage pregnancy affects women's investment in themselves and their children requires further examination. Adolescence is not only a period of skeletal growth. Adolescence is also a period of cognitive development and accruement of socioeconomic skills. How does precocious investment in reproduction, which I have shown limits maternal skeletal growth, affect investment in maternal cognitive development? (Tamimi et al., 2003). And, in a society like the Tsimane, where valuable resource accruement skills are learnt in adolescence, including parenting skills through time spent as alloparents, are women who delay reproduction better able to provide for their families and mother their children? Or, are these skills accruable whilst a teenage mother?

The effects of adolescent reproduction on the firstborn child and subsequent children also needs examination. In Chapter IV I showed that women that reproduce early are still investing in their own growth, strongly suggesting that their foetus and breastfeeding child are competing with them for resources. Do the foetuses and infants of adolescent mothers receive fewer resources than those of older mothers? Given maternal depletion, and possibly lower accruement of somatic stores during adolescences for early reproducers, do the latter born children of women who had their first child in adolescence receive fewer resources as foetuses and infants than the latter born children of women who had their first child at older ages? For example, are the children of precious reproducers smaller at birth, and do they show any cognitive deficits? Finally, given that male offspring may be more expensive (de Zegher, Devlieger, & Eeckels, 1999; Maršál et al., 1996; Tamimi et al., 2003), does the sex of the first born child, and subsequent children, affect the negative outcomes of precocious reproduction for the mother and her children?

C. Summary and furture directions

In summary, there are three main implications of this dissertation. First, simplistic accounts of how environmental cues should affect individual life history strategies are not supported by empirical findings. Secondly, women have distinct preferences for their sons and daughters that may be influenced by different environmental cues. Thirdly, whether adolescent reproduction harms women's and their children's socioeconomic status within their community is likely dependent on local culture – including how women's status is measured -- and women's and their children's socioeconomic mobility.

When exploring how mortality and education influence life history pace, the impact of a population's, and an individual's, ecology, socioeconomic standing and mobility, and cultural limitations must be considered. More work is needed to determine which specific environmental cues we are attuned to, how these cues interrelate, how context and culturally dependent the effects of cues are, how the timing and duration of exposure to cues influences their effects, and if there is sex specific variation in the aforementioned.

The research in this dissertation increases our understanding of women's fertility decisions and builds on theories of demographic transition, specifically the interplay between mortality and fertility at the onset of demographic transition, and Human Capital Theory, which focuses on changes in how resources are accrued and success measured (Kaplan, 1996; Voland, 1998). In addition, this research cross-cuts disciplines contributing to demographic transition studies in demography, sociology and anthropology. Working with Tsimane' women allowed for a better understanding of how market integration affects women's reproductive autonomy and rights, and thus how to assist women in transitioning societies to achieve their reproductive goals and improve their socioeconomic status. It is important to work with Tsimane' women now, while they are undergoing cultural and socioeconomic change, as the long-term outcomes may be detrimental to women's and children's health and socioeconomic standing.

The Tsimane' are an especially interesting case study due to the wealth of longitudinal data available, allowing for studies that ordinarily could not be done. Future studies should investigate the effects of market integration on reproductive preferences and behaviours over time, elucidating more fully why the demographic transition of so many Amerindians is not progressing as expected.

Future research should also have a focus that is of direct value to the Tsimane and to other indigenous populations. The Tsimane have expressed interest in understanding the long-term impacts of their high fertility, and in receiving education on family planning and maternal and child health. Furthermore, Tsimane' women are actively trying to improve their rights and socioeconomic status within Tsimane' and Bolivian society. Therefore, it is the onus of researchers to report our findings to the governments of the populations we work with, and related local and international organizations; and where appropriate, and desired by the local population, to provide public outreach programs on family planning and health.

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Appendix 1

Table 1. Total fertility rate calculations for Tsimane women born from 1943 to 1990. Taken from retrospective reproductive histories gathered by the Tsimane Life History Project from 2002 to 2008. Total fertility rates for women living near town, Mission, upper riverine, lower riverine and forest are shown.

Near town

Group #	Age Group	Total	# Births	ASFR	# Kids
1	<15	494	3	6.07	0.03
2	15-19	572	150	262.24	1.31
3	20-24	455	183	402.20	2.01
4	25-29	339	129	380.53	1.90
5	30-34	234	76	324.79	1.62
6	35-39	146	41	280.82	1.40
7	40-44	89	19	213.48	1.07
8	45-50	142	3	21.13	0.11
Total	<15-50	2471	604	1891.26	9.46

Mission

Group #	Age Group	Total	# Births	ASFR	# Kids
1	<15	268	2	7.46	0.04
2	15-19	316	74	234.18	1.17
3	20-24	249	104	417.67	2.09
4	25-29	170	73	429.41	2.15
5	30-34	123	43	349.59	1.75
6	35-39	92	26	282.61	1.41
7	40-44	54	13	240.74	1.20
8	45-50	62	1	16.13	0.08
Total	<15-50	1334	336	1977.79	9.89

Upper riverine

Group #	Age Group	Total	# Births	ASFR	# Kids
1	<15	360	0	0.00	0.00
2	15-19	424	81	191.04	0.96
3	20-24	335	137	408.96	2.04
4	25-29	225	82	364.44	1.82
5	30-34	170	64	376.47	1.88
6	35-39	122	45	368.85	1.84
7	40-44	87	23	264.37	1.32
8	45-50	76	0	0.00	0.00
Total	<15-50	1799	432	1974.13	9.87

Lower riverine

Group #	Age Group	Total	# Births	ASFR	# Kids
1	<15	272	6	22.06	0.11
2	15-19	324	81	250.00	1.25
3	20-24	245	95	387.76	1.94
4	25-29	193	74	383.42	1.92
5	30-34	146	48	328.77	1.64
6	35-39	111	43	387.39	1.94
7	40-44	58	15	258.62	1.29
8	45-50	102	4	39.22	0.20
Total	<15-50	1451	366	2057.22	10.29

Forest

Group #	Age Group	Total	# Births	ASFR	# Kids
1	<15	324	1	3.09	0.02
2	15-19	371	89	239.89	1.20
3	20-24	293	113	385.67	1.93
4	25-29	231	85	367.97	1.84
5	30-34	193	63	326.42	1.63
6	35-39	151	41	271.52	1.36
7	40-44	108	14	129.63	0.65
8	45-50	95	0	0.00	0.00
Total	<15-50	1766	406	1724.19	8.62

Table 2. Comparing parous women in this study against parous women in the same communities that did not participate in this study. Independent samples t-tests shown. Data for non-sampled women and educational data collected by the Tsimane Health and Life History Projects. The sample sizes vary as not all data was available for all women. Only parous women are compared as whether nulliparous women who were not sampled were truly nulliparous or just unrecorded by the Tsimane Life History Project is unknown.

	Sampled	N	Mean	±SD	*t*	*df*	*p*
Year of birth	No	199	1977.68	±13.62	-0.10	340	.917
	Yes	143	1977.84	±14.48			
Parity at time of interview[a]	No	199	5.42	±3.82	-1.41	340	.159
	Yes	143	6.04	±4.23			
Number of infant deaths at time of interview[a]	No	199	5.40	±3.83	-1.22	340	.222
	Yes	143	5.94	±4.20			
Age at first birth	No	176	17.81	±2.23	1.45	305	.147
	Yes	131	17.43	±2.35			
Spoken Spanish fluency[b]	No	185	0.60	±0.56	0.72	317	.475
	Yes	134	0.55	±0.63			
Spanish literacy[c]	No	185	0.48	±0.58	-0.16	317	.871
	Yes	134	0.50	±0.65			
Years of schooling	No	112	2.64	±3.10	0.89	189	.372
	Yes	79	2.20	±3.60			
Final school grade	No	185	2.05	±2.13	0.28	317	.779
	Yes	134	1.97	±2.47			

a. At time of interview is, for both sampled and non-sampled women, parity and infant mortality at the time women in their village were being interviewed.
b. Spanish fluency is measured on a three-point scale, with 0 indicating no fluency, 1 a little fluency, and 2 fluent.
c. Spanish literacy is measured on a three-point scale, with 0 indicating unable to read or write in Spanish, 1 indicating some ability to read or write in Spanish, and 2 that a person writes and reads well in Spanish.

Table 3. The positive associations between perceived own morbidity[b], and other perceived morbidity and infant mortality measures. Odds Ratios (OR) with 95% Wald Confidence Intervals (CI) shown for women's perceptions of mortality and morbidity.

Parameter	Model 1			Model 2			Model 3			Model 4		
		95% Wald CI			95% Wald CI			95% Wald CI			95% Wald CI	
	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Threshold												
Sick sometimes	0.38†	0.12	1.20	0.21*	0.06	0.74	0.32†	0.08	1.19	0.25*	0.08	0.81
Sick Often	2.23	0.71	6.97	1.98	0.60	6.58	1.73	0.47	6.44	1.35	0.43	4.31
Women's characteristics												
Distance to town	0.99	0.97	1.02	0.99	0.96	1.01	0.99	0.97	1.02	0.99	0.97	1.01
Education factor	1.22	0.86	1.75	1.40†	0.95	2.07	1.18	0.82	1.68	1.23	0.85	1.78
Parity-for-age-and-age2	0.74†	0.52	1.06	0.75	0.50	1.13	0.74†	0.52	1.06	0.74†	0.52	1.05
Child-deaths-for-parity	1.10	0.78	1.54	1.06	0.73	1.54	1.07	0.76	1.51	1.06	0.75	1.50
Perceived morbidity												
Local child morbidity[a]	**2.29***	1.09	4.83									
Own morbidity compared to others[c]												
Perceive self to be sick less often than others	-	-	-	**11.42*****	3.92	33.30	-	-	-	-	-	-
Perceive self to be sick more often than others	-	-	-	0.45†	0.19	1.05	-	-	-	-	-	-
Perceived mortality												
Local infant mortality[d]	-	-	-	-	-	-	1.13	0.55	2.32	-	-	-
Local child mortality[e]	-	-	-	-	-	-	-	-	-	0.78	0.36	1.68

† $p < 0.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived local child morbidity is for local children are often sick (N=39) compared to only sometimes sick (N=78).

b. Perceived own morbidity is for sometimes sick (N=45) or often sick (N=29) compared to rarely sick (N=43).

c. Perceived own morbidity compared to others is for ego sick less (N=45) or more (N=29) often than others compared to equally (N=43) often as others.

d. Perceived local infant mortality is for infants often die (N=72) compared to only sometimes die (N=47).

e. Perceived local child mortality is for children often die (N=33) in this community compared to only sometimes die (N=85).

Table 4. The positive associations between perceived own morbidity compared to other women[c], and perceived own morbidity and infant mortality measures. Odds Ratios (OR) with 95% Wald Confidence Intervals (CI) shown for women's perceptions of mortality and morbidity.

Parameter	Model 1			Model 2			Model 3			Model 4		
		95% Wald CI			95% Wald CI			95% Wald CI			95% Wald CI	
	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Threshold												
Sick less often than others	8.90***	2.45	32.28	10.77**	2.47	47.05	7.40***	1.91	28.69	4.88**	1.44	16.51
Sick more often than others	67.61***	15.95	286.67	99.06***	19.30	508.43	46.06***	10.45	202.95	29.58***	7.81	112.05
Women's characteristics												
Distance to town	1.05***	1.02	1.08	1.06***	1.03	1.09	1.05***	1.02	1.07	1.05***	1.02	1.07
Education factor	0.92	0.64	1.31	0.89	0.61	1.29	0.90	0.63	1.28	0.91	0.64	1.31
Parity-for-age-and-age2	0.63*	0.42	0.93	0.80	0.54	1.18	0.71†	0.49	1.02	0.68*	0.48	0.98
Child-deaths-for-parity	0.92	0.63	1.34	0.86	0.59	1.25	0.87	0.59	1.28	0.89	0.60	1.31
Perceived morbidity												
Local child morbidity[a]	**4.38*****	2.03	9.47	-	-	-	-	-	-	-	-	-
Own morbidity[b]												
Perceive self to sometimes be sick	-	-	-	0.63	0.27	1.48	-	-	-	-	-	-
Perceive self to often be sick	-	-	-	**8.16*****	3.11	21.44	-	-	-	-	-	-
Perceived mortality												
Local infant mortality[d]	-	-	-	-	-	-	1.68	0.81	3.47	-	-	-
Local child mortality[e]	-	-	-	-	-	-	-	-	-	1.12	0.51	2.47

† $p < 0.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived local child morbidity is for local children are often sick (N=39) compared to only sometimes sick (N=78).

b. Perceived own morbidity is for sometimes sick (N=48) or often sick (N=38) compared to rarely sick (N=36).

c. Perceived own morbidity compared to others is for ego sick less (N=45) or more (N=32) often than others compared to equally (N=44) often as others.

d. Perceived local infant mortality is for infants often die (N=72) compared to only sometimes die (N=47).

e. Perceived local child mortality is for children often die (N=33) in this community compared to only sometimes die (N=90).

Table 5. The positive associations between perceived infant mortality[d], and perceived morbidity and child mortality measures. Odds Ratios (OR) with 95% Wald Confidence Intervals (CI) shown for women's perceptions of mortality and morbidity.

Parameter	Model 1			Model 2			Model 3			Model 4		
		95% Wald CI			95% Wald CI			95% Wald CI			95% Wald CI	
	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Women's characteristics												
Distance to town	0.97†	0.95	1.00	0.97*	0.95	1.00	0.97*	0.94	0.99	0.97†	0.95	1.00
Education factor	1.46†	0.97	2.20	1.51*	1.00	2.26	1.50*	1.00	2.24	1.28	0.85	1.93
Parity-for-age-and-age2	0.68†	0.44	1.04	0.73	0.48	1.11	0.73	0.48	1.12	0.67†	0.44	1.02
Child-deaths-for-parity	1.10	0.74	1.63	1.09	0.75	1.60	1.12	0.76	1.64	1.13	0.77	1.67
Perceived morbidity												
Local child morbidity[a]	**3.05***	1.27	7.31	-	-	-	-	-	-	-	-	-
Own morbidity[b]												
Perceive self to sometimes be sick	-	-	-	1.23	0.44	3.39	-	-	-	-	-	-
Perceive self to often be sick	-	-	-	0.61	0.24	1.57	-	-	-	-	-	-
Own morbidity compared to others[c]												
Perceive self to be sick less often than others	-	-	-	-	-	-	2.31	0.79	6.75	-	-	-
Perceive self to be sick more often than others	-	-	-	-	-	-	1.30	0.49	3.43	-	-	-
Perceived mortality												
Local child mortality[e]	-	-	-	-	-	-	-	-	-	**4.81*****	1.63	14.24
Constant	4.31*			7.73**			6.56**			4.68*		

† $p < 0.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived local child morbidity is for local children are often sick (N=39) compared to only sometimes sick (N=78).

b. Perceived own morbidity is for sometimes sick (N=48) or often sick (N=38) compared to rarely sick (N=36).

c. Perceived own morbidity compared to others is for ego sick less (N=45) or more (N=32) often than others compared to equally (N=44) often as others.

d. Perceived local infant mortality is for infants often die (N=72) compared to only sometimes die (N=47).

e. Perceived local child mortality is for children often die (N=33) in this community compared to only sometimes die (N=90).

Table 6. The positive associations between perceived child mortality[e], and perceived morbidity and infant mortality measures. Odds Ratios (OR) with 95% Wald Confidence Intervals (CI) shown for women's perceptions of mortality and morbidity.

Parameter	Model 1			Model 2			Model 3			Model 4		
		95% Wald CI			95% Wald CI			95% Wald CI			95% Wald CI	
	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper	OR	Lower	Upper
Women's characteristics												
Distance to town	0.99	0.96	1.01	0.98	0.96	1.01	0.98	0.95	1.01	0.99	0.97	1.02
Education factor	1.84*	1.15	2.96	1.96**	1.19	3.23	2.03**	1.23	3.33	1.71*	1.06	2.78
Parity-for-age-and-age2	1.16	0.73	1.82	1.08	0.67	1.74	1.18	0.73	1.89	1.30	0.80	2.12
Child-deaths-for-parity	0.98	0.63	1.51	0.96	0.61	1.51	0.97	0.62	1.50	0.91	0.58	1.45
Perceived morbidity												
Local child morbidity[a]	1.00	0.42	2.41	-	-	-	-	-	-	-	-	-
Own morbidity[b]												
Perceive self to sometimes be sick	-	-	-	0.76	0.24	2.43	-	-	-	-	-	-
Perceive self to often be sick	-	-	-	1.56	0.55	4.42	-	-	-	-	-	-
Own morbidity compared to others[c]												
Perceive self to be sick less often than others	-	-	-	-	-	-	1.37	0.42	4.46	-	-	-
Perceive self to be sick more often than others	-	-	-	-	-	-	0.96	0.32	2.84	-	-	-
Perceived mortality												
Local infant mortality[d]	-	-	-	-	-	-	-	-	-	**4.70****	1.59	13.90
Constant	0.59			0.62			0.73			0.16*		

† $p < 0.10$, * $p < .05$, ** $p < .01$, *** $p < .001$

a. Perceived local child morbidity is for local children are often sick (N=39) compared to only sometimes sick (N=78).

b. Perceived own morbidity is for sometimes sick (N=48) or often sick (N=38) compared to rarely sick (N=36).

c. Perceived own morbidity compared to others is for ego sick less (N=45) or more (N=32) often than others compared to equally (N=44) often as others.

d. Perceived local infant mortality is for infants often die (N=72) compared to only sometimes die (N=47).

e. Perceived local child mortality is for children often die (N=33) in this community compared to only sometimes die (N=90)

Table 7. General linear mixed method models comparing the relationship between mortality and morbidity variables and women's preferred age at first birth for their sons. The symbols indicate the direction of the relationship between the variable in the model and women's preferred age at first birth for their sons. A + symbol indicates a positive relationship and a – symbol a negative relationship. Red symbols are significant with one symbol meaning a *p-value* ≤0.05 to >0.01, two a *p-value* ≤0.01 to >0.001, and three a *p-value* ≤0.001. Green symbols represent p-values ≤0.10 to >0.05, and black symbols represent non-significant p-values that are >0.10.

Model No.	Distance to town	Education factor	Age	Age at first birth	Parity-for-age	Infant deaths-for-parity	Mother's parity	Mother's infant deaths-for-parity	Perceived child morbidity in community	Perceived own morbidity	Perceived own morbidity compared to others	Perceived local infant mortality	Perceived local child mortality	K	AIC	AICc	Δi	wi
Base Model																		
1	- - -	+	+											5	640.934	641.465	71.045	0.000
Experiences of own reproduction																		
2	- -	+	+	+										6	569.572	570.42	0.000	0.520
3	- - -	+	+		+										642.4179	643.168	72.748	0.000
4	- -	+	+	+	+										570.214	571.357	0.937	0.325
Experiences of own infant death																		
5	- - -	+	+	+		+								7	643.4402	644.450	74.029	0.000
6	- - -	+	+		+	+									643.623	644.632	74.212	0.000
7	- - -	+	+	+	+	+								8	571.362	572.846	2.426	0.155
Perceived morbidity and mortality																		
8	- - -	+	+						-					6	640.987	641.737	71.317	0.000
9	- - -	+	+							+/+				8	640.122	641.140	70.720	0.000
10	- - -	+	+								-/-			8	640.095	641.114	70.694	0.000
11	- - -	+	+									+		7	642.924	643.674	73.254	0.000
12	- - -	+	+										+	7	636.997	637.747	67.327	0.000
Experiences of sibling infant deaths (random effect of same mother)																		
13	- -	+	+											6		650.632	15.288	0.000
14	- -	+	+				+							7		643.436	8.092	0.013
15	- -	+	+				+	+						8		643.492	8.148	0.013
16	- -	+	+		+	+	+	+						10		642.925	7.581	0.017
Perceived morbidity and mortality (mother's infant deaths-for-parity included)																		
17	- -	+	+				+	+	-					9		640.494	5.150	0.058
18	- -	+	+				+	+		+/+				9		640.692	5.348	0.052
19	- -	+	+				+	+			-/-			9		640.33	4.986	0.063
20	- -	+	+				+	+				+		9		642.252	6.908	0.024
21	- -	+	+				+	+					++	9		635.344	0.000	0.759

Table 8. Comparing general linear mixed models for the relationship between the mortality and morbidity variables and women's preferred age at first birth for their daughters. The symbols indicate the direction of the relationship between the variable in the model and women's preferred age at first birth for their daughters. A + symbol indicates a positive relationship and a – symbol a negative relationship. Red symbols are significant with one symbol meaning a *p-value* ≤0.05 to >0.01, two a *p-value* ≤0.01 to >0.001, and three a *p-value* ≤0.001. Green symbols represent p-values ≤0.10 to >0.05, and black symbols represent non-significant p-values that are >0.10.

Model No.	Distance to town	Education factor	Age	Age at first birth	Parity-for-age	Infant deaths-for-parity	Mother's parity	Mother's infant deaths-for-parity	Perceived child morbidity in community	Perceived own morbidity	Perceived own morbidity compared to others	Perceived local infant mortality	Perceived local child mortality	K	AIC	AIC_c	Δ_i	w_i
Base Model																		
1	-	-	+											5	611.684	612.201	60.803	0.000
Experiences of own reproduction																		
2	-	-	+	-										6	557.350	558.174	6.776	0.018
3	-	-	+		-									6	608.683	609.4133	58.015	0.000
4	-	-	+	-	-									7	558.139	559.248	7.850	0.010
Experiences of own infant death																		
5	-	-	+	-		+ +								7	550.646	551.755	0.357	0.443
6	-	-	+		-	+ + +									603.511	604.493	53.095	0.000
7	**-**	**-**	**+**	**-**	**-**	**+ + +**								**8**	**549.958**	**551.398**	**0.000**	**0.529**
Perceived morbidity and mortality																		
8	-	-	+		-	+ + +			-					8	598.991	600.276	48.878	0.000
9	-	-	+		-	+ + +				+/+				9	595.221	596.843	45.445	0.000
10	-	-	+		-	+ + +					-/+			9	592.552	594.174	42.776	0.000
11	-	-	+		-	+ + +						+		8	603.664	604.938	53.540	0.000
12	-	-	+		-	+ + +							+	8	602.545	603.819	52.421	0.000
Experiences of sibling infant deaths (random effect of same mother)																		
13	-	-	+											6		623.367	37.919	0.000
14	-	-	+				+							7		603.598	18.150	0.000
15	-	-	+				+	+						8		600.773	15.325	0.000
16	-	-	+		-	+ +	+	+						10		589.848	4.400	0.036
Perceived morbidity and mortality (mother's infant deaths-for-parity included)																		
17	-	-	+		-	+ +	+	+	-					11		588.297	2.849	0.077
18	-	-	+		-	+ +	+	+		+/+				11		587.688	2.240	0.105
19	-	-	+		-	+ +	+	+			+/+			11		585.704	0.256	0.283
20	-	-	+		-	+ +	+	+				+		11		586.627	1.179	0.178
21	**-**	**-**	**+**		**-**	**+ +**	**+**	**+**					**+**	**11**		**585.448**	**0.000**	**0.321**

Table 9. Comparing general linear mixed models for the relationship between the mortality and morbidity variables and women's preferred interbirth intervals for themselves. The symbols indicate the direction of the relationship between the variable in the model and women's preferred interbirth interval for themselves. A + symbol indicates a positive relationship and a – symbol a negative relationship. Red symbols are significant with one symbol meaning a *p-value* ≤0.05 to >0.01, two a *p-value* ≤0.01 to >0.001, and three a *p-value* ≤0.001. Green symbols represent p-values ≤0.10 to >0.05, and black symbols represent non-significant p-values that are >0.10. Note, models 2 and 3 are not included for AIC comparisons as they have a much smaller sample size.

Model No.	Distance to town	Education factor	Age	Mean interbirth interval	Parity-for-age	Infant deaths-for-parity	Mother's parity	Mother's infant deaths-for-parity	Perceived child morbidity in community	Perceived own morbidity	Perceived own morbidity compared to others	Perceived local infant mortality	Perceived local child mortality	K	AIC	AIC_c	Δ_i	w_i
Base Model																		
1	-	+	+											5	288.545	289.151	85.732	0.017
Experiences of own reproduction																		
2	-	+	+	+										6	202.106	203.419		
3	-	+	+	+	+									7	204.076	205.854		
4	-	+	+		-									6	290.435	291.2924	87.873	0.006
Experiences of own infant death																		
5	-	+	+			-								6	290.046	290.9032	87.484	0.007
6	-	+	+		+	+								7	291.878	293.0325	89.614	0.002
Perceived morbidity and mortality																		
7	-	+	+						+					6	288.158	289.0235	85.605	0.018
8	-	+	+							-/-				6	285.396	286.562	83.143	0.062
9	-	+	+								+/++			6	**280.102**	**281.269**	**77.850**	**0.871**
10	-	+	+									+		6	290.123	290.9805	87.562	0.007
11	-	+	+										+	6	289.341	290.1977	86.779	0.010
Experiences of sibling infant deaths (random effect of same mother)																		
12	-	+	+											5		305.221	11.051	0.002
13	-	+	+				-							6		297.236	3.066	0.135
14	-	+	+				-	-						7		298.989	4.819	0.056
15	-	+	+		-	-	-	-						9		303.715	9.545	0.005
Perceived morbidity and mortality (mother's infant deaths-for-parity included)																		
16	-	+	+				-	-	+					8		300.275	6.105	0.030
17	-	+	+				-	-		-/-				8		298.325	4.155	0.078
18	-	+	+				-	-			+/++			8		294.170	0.000	0.626
19	-	+	+				-	-				+		8		300.277	6.107	0.030
20	-	+	+				-	-					+	8		299.775	5.605	0.038

Table 10. Comparing binary logistic mixed models for the relationship between the mortality and morbidity variables and women's preferred family size for their sons (few versus many children). The symbols indicate the direction of the relationship between the variable in the model and whether women preferred few (coded as 0) or many (coded as 1) children for their sons. A + symbol indicates a positive relationship and a – symbol a negative relationship. Red symbols are significant with one symbol meaning a *p-value* ≤0.05 to >0.01, two a *p-value* ≤0.01 to >0.001, and three a *p-value* ≤0.001. Green symbols represent p-values ≤0.10 to >0.05, and black symbols represent non-significant p-values that are >0.10.

Model No.	Distance to town	Education factor	Age	Parity-for-age	Infant deaths-for-parity	Mother's parity	Mother's infant deaths-for-parity	Perceived child morbidity in community	Perceived own morbidity	Perceived own morbidity compared to others	Perceived local infant mortality	Perceived local child mortality	K	AIC	AIC$_c$	Δ_i	w_i
Base Model																	
1	-	- - -	-										5	107.178	107.532	2.580	0.063
Experiences of own reproduction																	
2	-	- - -	-	+									6	105.749	106.2845	1.333	0.117
Experiences of own infant death																	
3	-	- - -	-	+	+								6	106.587	107.344	2.392	0.069
Perceived morbidity and mortality																	
4	**-**	**- - -**	**-**	**+**				**+**					**7**	**104.330**	**105.094**	**0.142**	**0.212**
5	-	- - -	-	+					-/+				7	106.615	107.643	2.691	0.059
6	**-**	**- - -**	**-**	**+**						**+/+**			**7**	**103.924**	**104.952**	**0.000**	**0.227**
7	-	- - -	-	+							-		7	107.176	107.933	2.981	0.051
8	**-**	**- - -**	**-**	**+**								**+**	**7**	**104.428**	**105.185**	**0.233**	**0.202**
Experiences of sibling infant deaths (random effect of same mother)																	
9	-	- - -	-										5		600.416	14.872	0.000
10	-	- - -	-										6		642.939	57.395	0.000
11	-	- - -	-			-							7		619.354	33.810	0.000
12	-	- - -	-			-	+						8		587.032	1.488	0.188
13	-	- - -	-	x	+	-	+						9		590.099	4.555	0.041
Perceived morbidity and mortality (mother's infant deaths-for-parity included)																	
14	-	- - -	-	x		-	+	+					9		601.427	15.883	0.000
15	-	- - -	-	x		-	+		-/+				9		585.544	0.000	0.396
16	-	- - -	-	x		-	+			+/+			9		586.978	1.434	0.193
17	-	- - -	-	x		-	+				-		9		587.113	1.569	0.181
18	-	- - -	-	x		-	+					+	9		603.099	17.555	0.000

Table 11. Comparing binary logistic mixed models for the relationship between the mortality and morbidity variables and women's preferred family size for their daughters (few versus many children). The symbols indicate the direction of the relationship between the variable in the model and whether women preferred few (coded as 0) or many (coded as 1) children for their daughters. A + symbol indicates a positive relationship and a – symbol a negative relationship. Red symbols are significant with one symbol meaning a *p-value* ≤0.05 to >0.01, two a *p-value* ≤0.01 to >0.001, and three a *p-value* ≤0.001. Green symbols represent p-values ≤0.10 to >0.05, and black symbols represent non-significant p-values that are >0.10.

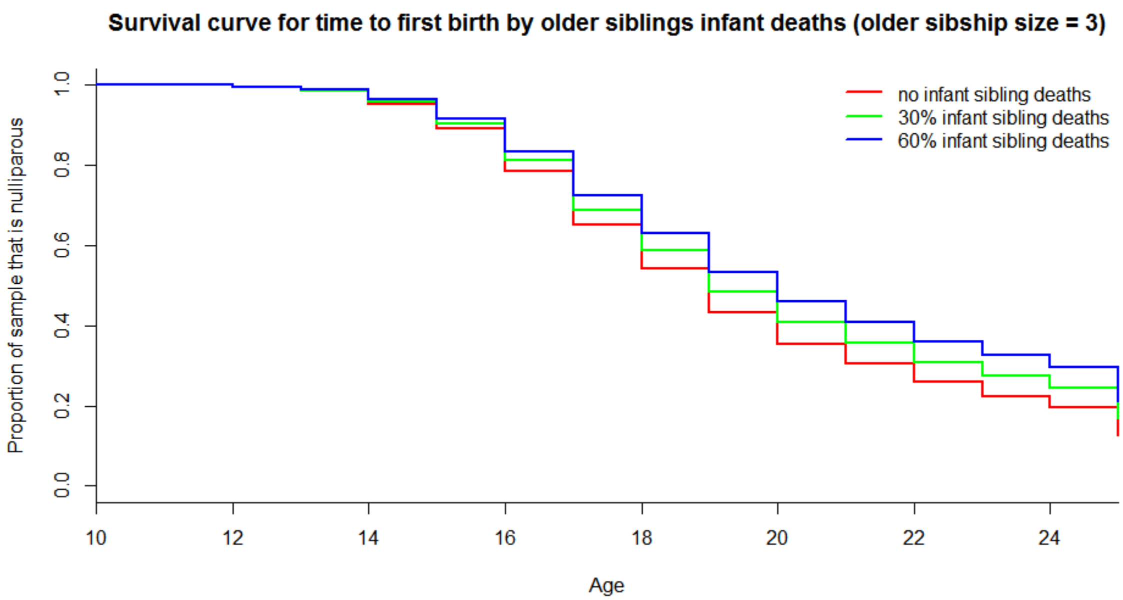
Model No.	Distance to town	Education factor	Age	Parity-for-age	Infant deaths-for-parity	Mother's parity	Mother's infant deaths-for-parity	Perceived child morbidity in community	Perceived own morbidity	Perceived own morbidity compared to others	Perceived local infant mortality	Perceived local child mortality	K	AIC	AIC_c	Δ_i	w_i
Base Model																	
1	**-**	**- - -**	**-**										**5**	**106.100**	**106.442**	**0.913**	**0.247**
Experiences of own reproduction																	
2	-	- - -	-	+									6	108.072	108.589	3.060	0.085
Experiences of own infant death																	
3	-	- - -	-	-	+								6	107.737	108.467	2.938	0.090
Perceived morbidity and mortality																	
4	-	- - -	-	+				+					7	108.072	108.809	3.280	0.076
5	-	- - -	-	+					-/+				7	110.245	111.236	5.707	0.022
6	-	- - -	-	+						+/+			7	108.928	109.919	4.390	0.043
7	-	- - -	-	+							-		7	109.051	109.782	4.253	0.047
8	**-**	**- - -**	**-**	**+**								**+**	**7**	**104.799**	**105.529**	**0.000**	**0.390**
Experiences of sibling infant deaths (random effect of same mother)																	
9	-	- - -	-										5		619.510	16.825	0.000
10	-	- -	-										6		614.920	12.235	0.002
11	-	- -	-			+							7		602.685	0.000	0.957
12	-	- -	-			+	+						8		612.334	9.649	0.008
13	-	- - -	-		+	+	+						9		614.364	11.679	0.003
Perceived morbidity and mortality (mother's infant deaths-for-parity included)																	
14	-	- -	-			-	+	+					9		611.224	8.539	0.013
15	-	- -	-			+	+		-/-				9		614.381	11.696	0.003
16	-	- -	-			-	+			+/+			9		612.427	9.742	0.007
17	-	- -	-			+	+				-		9		612.597	9.912	0.007
18	-	- -	-			+	+					+	9		624.715	22.030	0.000

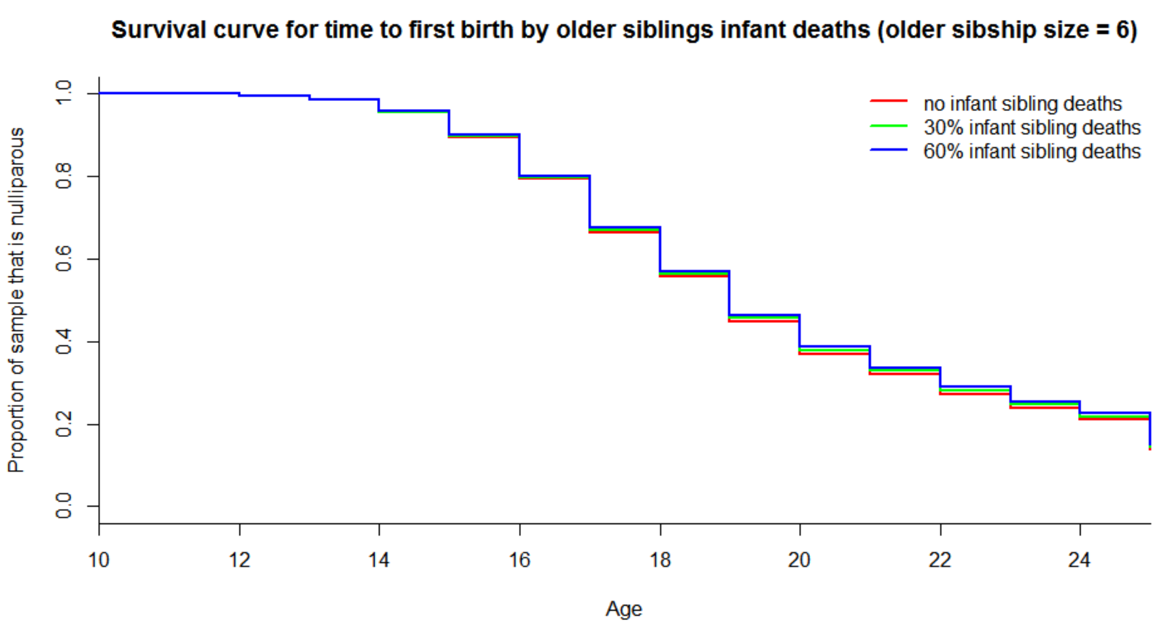
Table 12. Cox's regression of the effect of infant sibling deaths on progression to second birth by whether the sibling infant deaths occurred before or after a woman was born. Frailty term for family membership (N = 408) included in model to control for same family environment among sisters. Sibship size and sibship deaths are either from before a woman was born or from when a woman was born to her first birth. Model 1 is the same as Table 8 in Chapter 3.

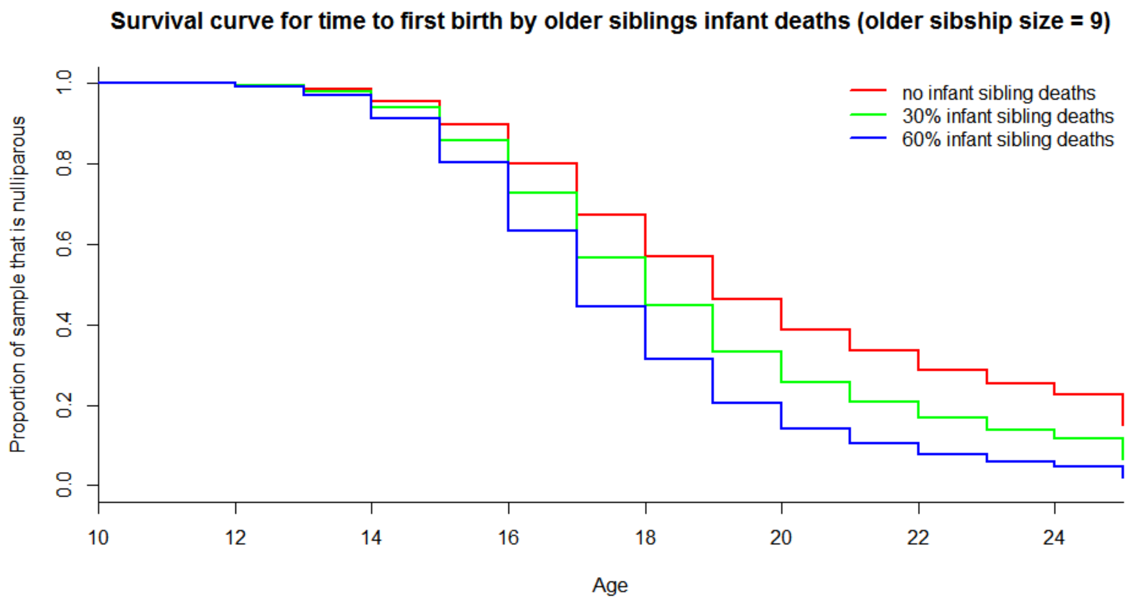
Variable	Model 1 β (S.E.)	Model 2 β (S.E.)	Model 3 β (S.E.)
Distance to town (km)	0.001 (0.002)	0.001 (0.002)	0.001 (0.002)
Age	0.344 (0.061)***	0.335 (0.060)***	0.340 (0.061)***
Age2	-0.005 (0.001)***	-0.005 (0.001)***	-0.005 (0.001)***
Birth Order	0.002 (0.018)	-	0.034 (0.017)*
Woman's age at first birth	-0.058 (0.018)***	-0.055 (0.018)**	-0.060 (0.018)***
All siblings born before woman's first birth			
Number of siblings	0.004 (0.022)	-	-
Number of dead siblings	-0.320 (0.145)*	-	-
Siblings*sibling deaths	0.036 (0.014)*	-	-
Before woman born			
Number of siblings	-	0.015 (0.018)	-
Number of dead siblings	-	-0.213 (0.153)	-
Siblings*sibling deaths	-	0.033 (0.022)	-
After woman born			
Number of siblings	-	-	0.019 (0.022)
Number of dead siblings	-	-	-0.076 (0.149)
Siblings*sibling deaths	-	-	0.018 (0.018)
Frailty term (mother's ID)	NS	NS	NS
AIC	10.404 6177.768	8.995 6184.358	9.800 6183.073
McFadden pseudo R2	0.017	0.015	0.016

† *p* <.10, * *p* <.05, ** *p* <.01, *** *p* <.001

Figure 1. The positive association between the interaction term older siblings*older sibling deaths and effect on women's age at first birth. Sibship size fixed at 3, 6, 9 and 12, with 0%, 30% or 60% of siblings dying. When women have relatively few older siblings the effect of older siblings dying in infancy on women's age at first birth are muted, such that women have even older ages at first birth. When women have relatively many older siblings the effect of older siblings dying in infancy is exaggerated, such that women have younger ages at first birth.






Survival curve for time to first birth by older siblings infant deaths (older sibship size = 9)
Proportion of sample that is nulliparous
Age
no infant sibling deaths
30% infant sibling deaths
60% infant sibling deaths
0.0
0.2
0.4
0.6
0.8
1.0
10
12
14
16
18
20
22
24

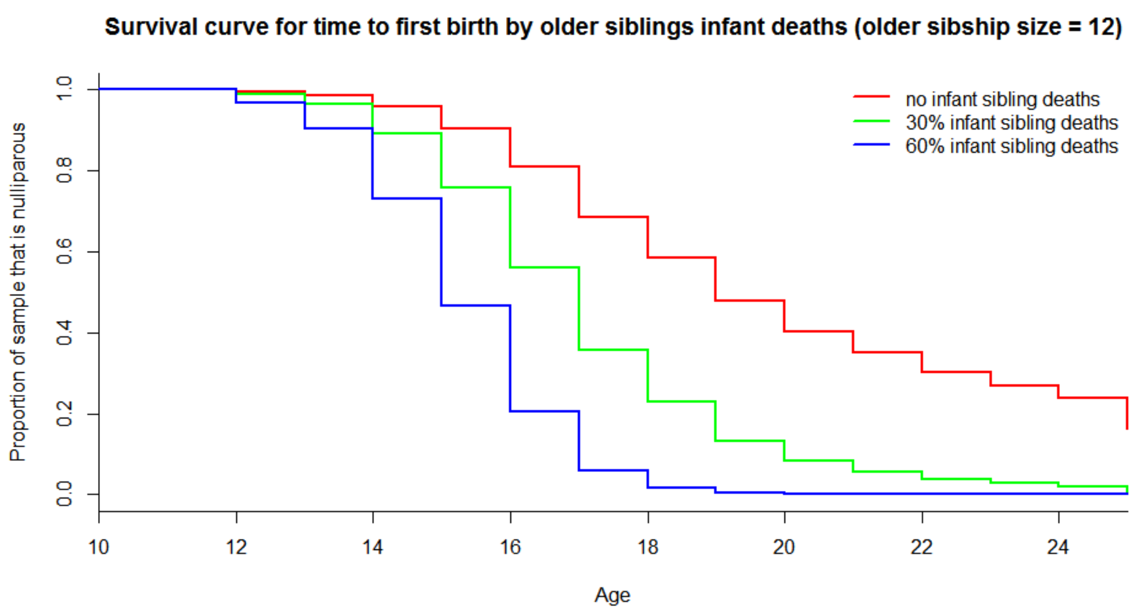
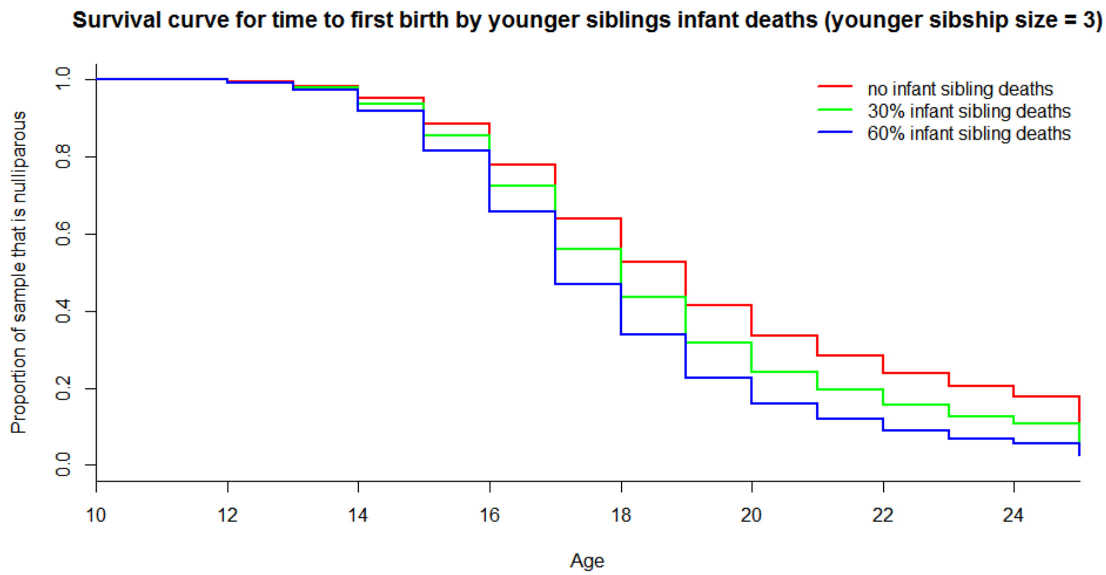
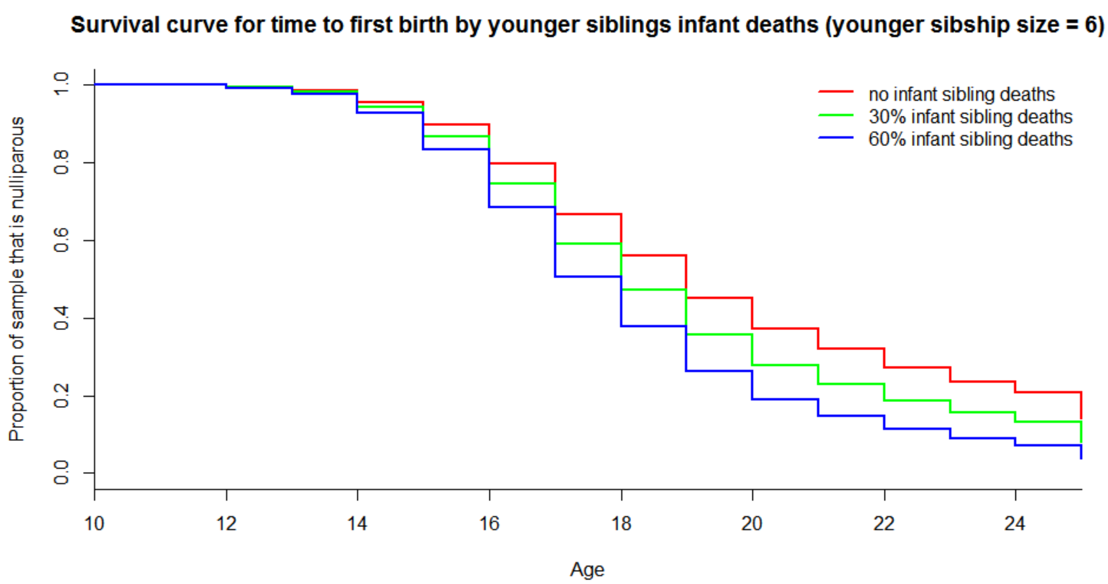
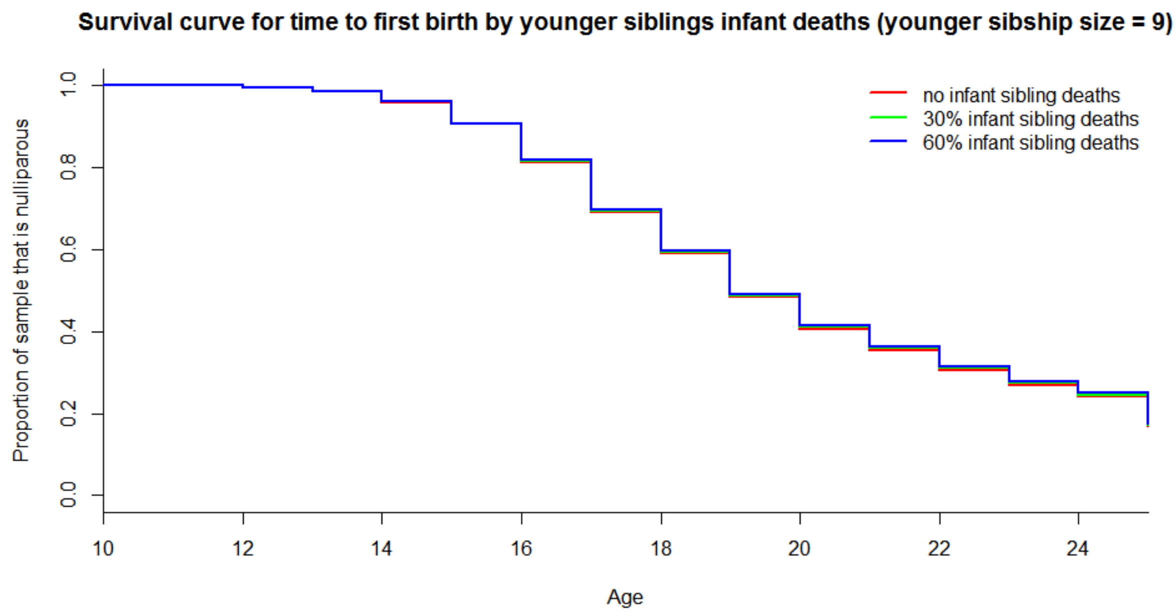

Survival curve for time to first birth by older siblings infant deaths (older sibship size = 12)
Proportion of sample that is nulliparous
Age
no infant sibling deaths
30% infant sibling deaths
60% infant sibling deaths
0.0
0.2
0.4
0.6
0.8
1.0
10
12
14
16
18
20
22
24

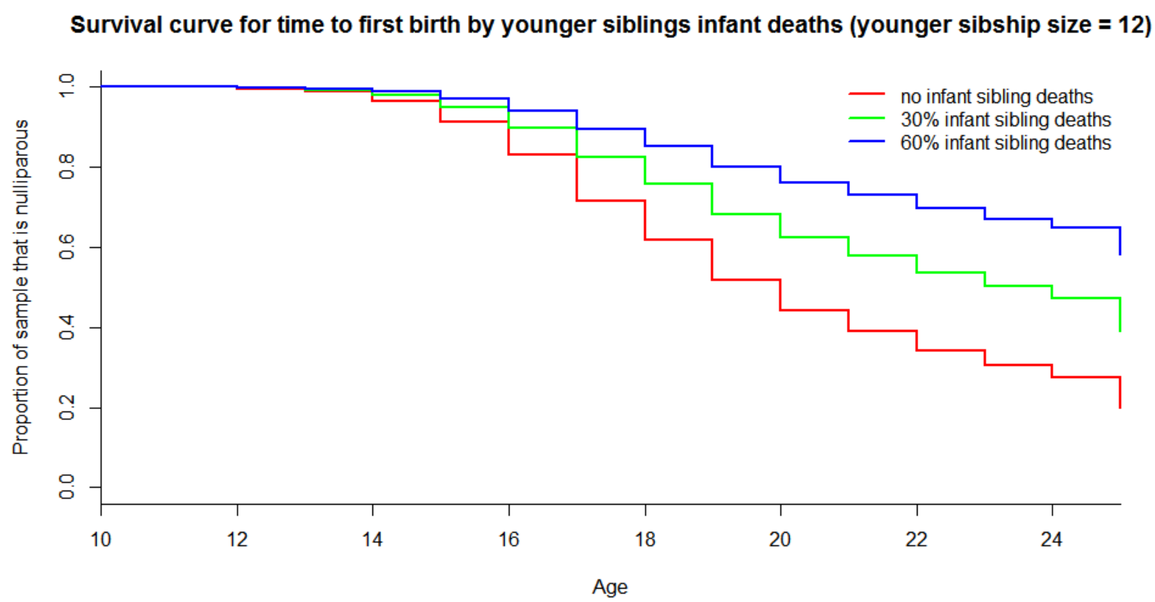
Figure 2. The negative association between the interaction term younger siblings*younger sibling deaths and effect on women's age at first birth. Sibship size fixed at 3, 6, 9 and 12, with 0%, 30% or 60% of siblings dying. When women have relatively few younger siblings the effect of younger siblings dying in infancy on women's age at first birth are exaggerated, such that women have even younger ages at first birth. When women have relatively many younger siblings the effect of younger siblings dying in infancy is muted, such that women have older ages at first birth than expected.





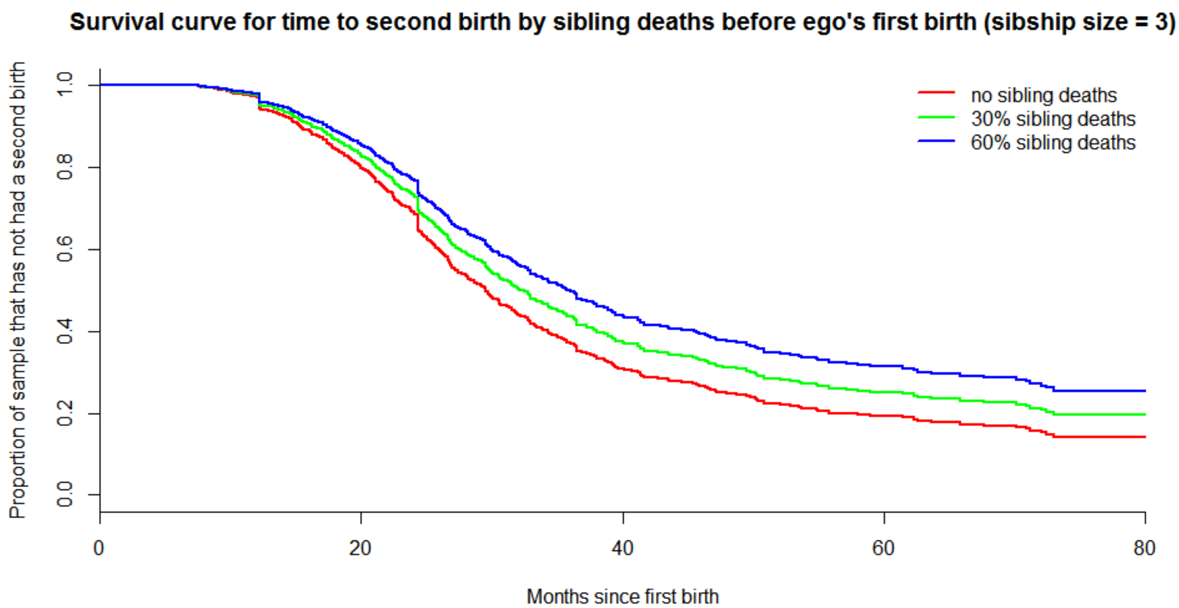


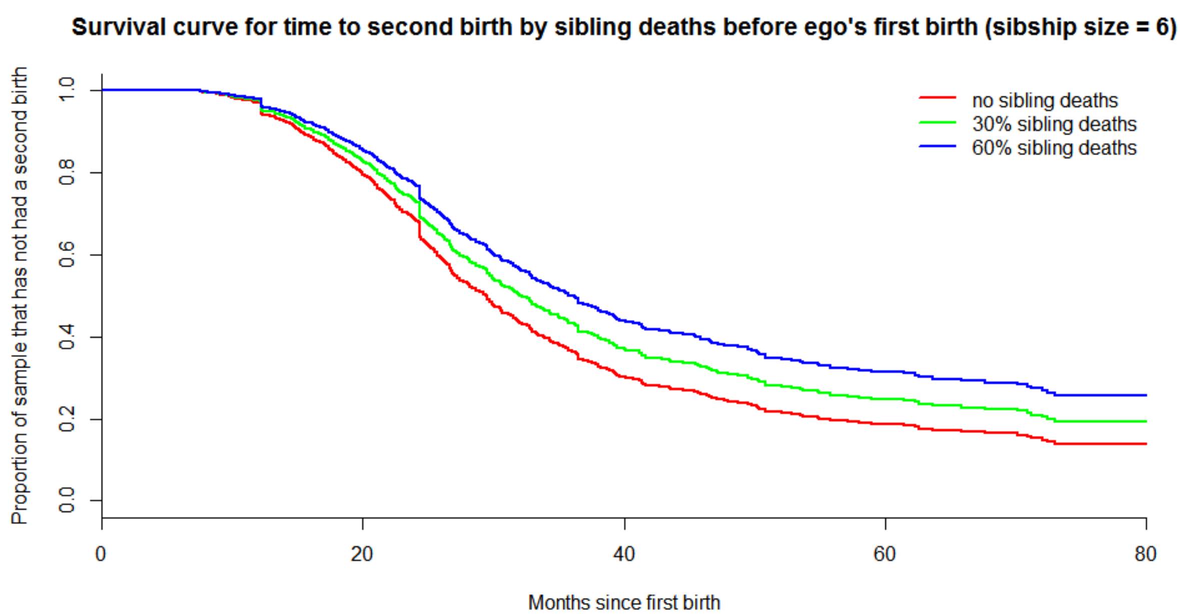
Survival curve for time to first birth by younger siblings infant deaths (younger sibship size = 9)
no infant sibling deaths
30% infant sibling deaths
60% infant sibling deaths
Proportion of sample that is nulliparous
0.0
0.2
0.4
0.6
0.8
1.0
10
12
14
16
18
20
22
24
Age

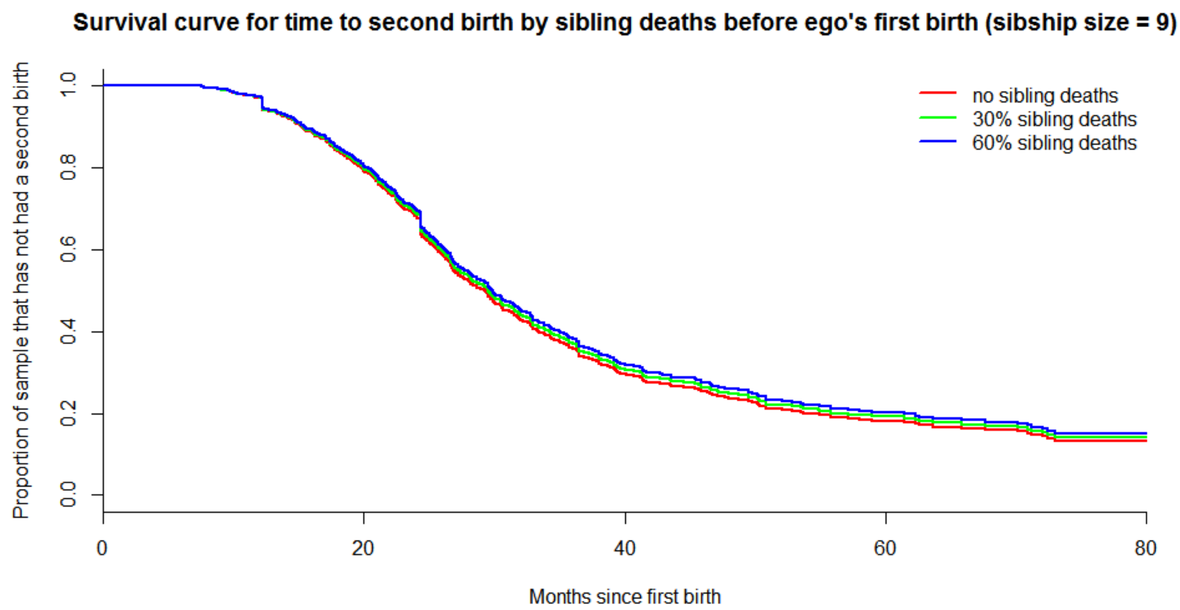


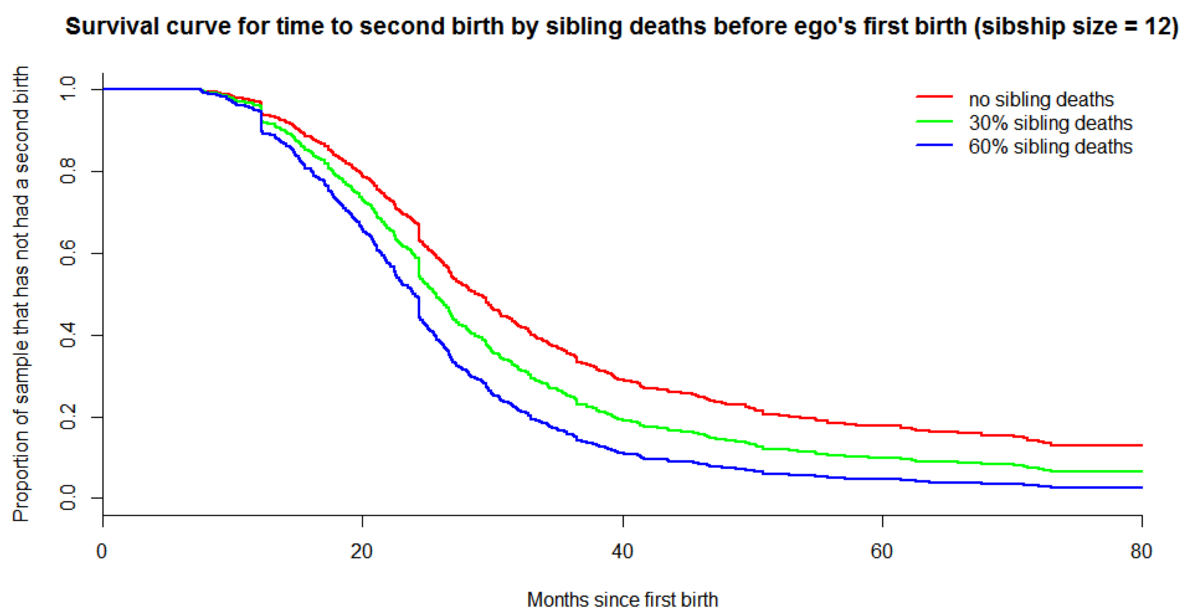
Survival curve for time to first birth by younger siblings infant deaths (younger sibship size = 12)
no infant sibling deaths
30% infant sibling deaths
60% infant sibling deaths
Proportion of sample that is nulliparous
0.0
0.2
0.4
0.6
0.8
1.0
10
12
14
16
18
20
22
24
Age

Figure 3. The positive association between the interaction term siblings* sibling deaths and effect on progression to second birth. Sibship size fixed at 3, 6, 9 and 12, with 0%, 30% or 60% of siblings dying. When women have relatively few siblings the effect of siblings dying in infancy on women's age at first birth are exaggerated, such that women have even longer times to second birth. When women have relatively many siblings the effect of siblings dying in infancy is muted, such that women have shorter times to second birth than expected.






Survival curve for time to second birth by sibling deaths before ego's first birth (sibship size = 9)
Proportion of sample that has not had a second birth
Months since first birth
no sibling deaths
30% sibling deaths
60% sibling deaths
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80


Survival curve for time to second birth by sibling deaths before ego's first birth (sibship size = 12)
Proportion of sample that has not had a second birth
Months since first birth
no sibling deaths
30% sibling deaths
60% sibling deaths
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80

Appendix 2

Table 1. List and description of variables used to measure women's educational capital and level of market integration, and the control variables age and parity.

Variables	N	Mean	±SD	Type	Description	Coding
Women's characteristics						
Age	172	32.45	±14.80	continuous	Woman's age at time of interview.	NA
Parity	154	5.90	±4.05	continuous	Woman's number of live births at time of interview.	NA
Level of market integration						
Educational capital						
Years of schooling	172	0.62	±0.49	continuous	Number of years a woman attended school	NA
Spanish literacy	172	1.54	±0.64	categorical	Ability to read and write in Spanish	0 = unable to read or write, 1 = some ability to read or write, 2 = writes and reads well.
Spoken Spanish fluency	172	1.48	±0.62	categorical	Ability to speak Spanish	0 = no fluency, 1 = a little fluency, 2 = fluent.
Access to town						
Proximity to town	171	48.29	±15.52	continuous	Distance from center of community to center of nearest town as the crow flies was subtracted from the furthest distance from town. In km.	NA
How often visits town	129	2.94	±1.07	categorical	How often a woman visits town	1 = never, 2 = once per year, 3 = a few times per year, 4 = once per month, 5 = twice per month, 6 = once per week
Visits town without a male relative	126	1.40	±0.79	categorical	How often a woman has visited town unaccompanied by a male relative or her husband.	1 = never, 2 = rarely, 3 = sometimes, 4 = often, 5 = always
Ownership of luxury items						
Number of luxury items owned	121	4.73	±3.35	continuous	How many of the following were owned by household members: moped, bicycle, television, radio, cell phone, watch, shoes (belonging to ego), mosquito net (over ego's bed), large metal cooking pots, fishing net, flashlight or lamp, chainsaw.	NA
Number of types of luxury items owned	121	0.91	±1.22	continuous	Number of different types of luxury items owned regardless of how many of each item.	NA
Importance of owning luxury items	121	21.05	±2.90	continuous	For each luxury item women were asked how important owning the item was (1 = not important, 2 = somewhat important, 3 = important). This is the sum for all items.	NA
Access to wage labor (separated by sex in analyses)						
Wage labor is available for men	125	0.72	±0.45	binary	Whether a woman believes Tsimane men can get jobs	0 = no, 1 = yes
Possible for men to earn money	125	0.95	±0.21	binary	Whether a woman believes Tsimane men can earn money	0 = no, 1 = yes
Wage labor is available for women	125	0.50	±0.50	binary	Whether a woman believes Tsimane women can get jobs	0 = no, 1 = yes
Possible for women to earn money	125	0.71	±0.46	binary	Whether a woman believes Tsimane women can earn money	0 = no, 1 = yes

Table 2. Correlation matrix of the eleven questions that assessed women's level of market integration.

		Age	Parity	Years of schooling	Spanish literacy	Spoken Spanish fluency	Proximity to town	How often visits town	Can visit town without a male relative	Number of luxury items owned	Number of different types of luxury items owned	Importance of owning luxury items	Believes wage labor is available for women	Believes it is possible for women to earn money	Believes wage labor is available for men	Believes it is possible for men to earn money
Age	Pearson *r*	1	.763***	-.313***	-.257***	-.181*	-.166*	-.014	-.100	.126	.126	-.067	-.002	-.103	-.063	.074
	N	172	154	171	172	172	171	129	126	121	121	121	125	125	125	125
Parity	Pearson *r*	.763***	1	-.267***	-.296***	-.240**	-.082	-.071	-.100	.184	.193*	.026	-.029	-.145	-.028	.105
	N	154	154	153	154	154	153	114	113	106	106	106	110	110	110	110
Years of schooling	Pearson *r*	-.313***	-.267***	1	.680***	.534***	-.010	.049	.142	.100	-.020	.185*	.185*	.000	.313***	-.054
	N	171	153	171	171	171	170	128	125	121	121	121	124	124	124	124
Spanish literacy	Pearson *r*	-.257***	-.296***	.680***	1	.740***	.122	.161	.075	.170	.056	.262**	.170	-.064	.344***	-.129
	N	172	154	171	172	172	171	129	126	121	121	121	125	125	125	125
Spoken Spanish fluency	Pearson *r*	-.181*	-.240**	.534***	.740***	1	.141	.112	.226*	.149	.011	.208*	.164	-.100	.269**	-.159
	N	172	154	171	172	172	171	129	126	121	121	121	125	125	125	125
Proximity to town	Pearson *r*	-.166*	-.082	-.010	.122	.141	1	.498***	.432***	.217*	.151	.373***	-.081	-.170	.002	-.056
	N	171	153	170	171	171	171	129	126	121	121	121	125	125	125	125
How often visits town	Pearson *r*	-.014	-.071	.049	.161	.112	.498***	1	.379***	.245*	.119	.220*	-.147	-.242**	-.019	-.164
	N	129	114	128	129	129	129	129	126	102	102	102	125	125	125	125
Can visit town without a male relative	Pearson *r*	-.100	-.100	.142	.075	.226*	.432***	.379***	1	.203*	.191	.208*	.019	-.151	.040	-.162
	N	126	113	125	126	126	126	126	126	99	99	99	122	122	122	122
Number of luxury items owned	Pearson *r*	.126	.184	.100	.170	.149	.217*	.245*	.203*	1	.816***	.359***	.033	-.101	.128	-.020
	N	121	106	121	121	121	121	102	99	121	121	121	99	99	99	99
Number of different types of luxury items owned	Pearson *r*	.126	.193*	-.020	.056	.011	.151	.119	.191	.816***	1	.238**	-.100	-.182	.040	-.112
	N	121	106	121	121	121	121	102	99	121	121	121	99	99	99	99
Importance of owning luxury items	Pearson *r*	-.067	.026	.185*	.262**	.208*	.373***	.220*	.208*	.359***	.238**	1	.090	-.059	.031	-.091
	N	121	106	121	121	121	121	102	99	121	121	121	99	99	99	99
Believes wage labor is available for women	Pearson *r*	-.002	-.029	.185*	.170	.164	-.081	-.147	.019	.033	-.100	.090	1	.560***	.120	.148
	N	125	110	124	125	125	125	125	122	99	99	99	125	125	125	125
Believes it is possible for women to earn money	Pearson *r*	-.103	-.145	.000	-.064	-.100	-.170	-.242**	-.151	-.101	-.182	-.059	.560***	1	-.121	.270**
	N	125	110	124	125	125	125	125	122	99	99	99	125	125	125	125
Believes wage labor is available for men	Pearson *r*	-.063	-.028	.313***	.344***	.269**	.002	-.019	.040	.128	.040	.031	.120	-.121	1	.110
	N	125	110	124	125	125	125	125	122	99	99	99	125	125	125	125
Believes it is possible for men to earn money	Pearson *r*	.074	.105	-.054	-.129	-.159	-.056	-.164	-.162	-.020	-.112	-.091	.148	.270**	.110	1
	N	125	110	124	125	125	125	125	122	99	99	99	125	125	125	125

$* = p < 0.05$, $** = p < 0.01$, $*** = p < 0.001$

Table 3. List and description of variables used to measure women's perceived returns to educational capital investments, and reproductive preferences for children.

Variables	N	Sons Mean	Sons ±SD	Daughters Mean	Daughters ±SD	Type	Description	Coding
Perceived returns on educational capital investments (separated by sex of child talking about in analyses)								
Perceived number of negative outcomes of being educated	125	4.74	±0.73	2.22	±1.29	continuous	Women were asked to free-list what they thought were the positive and negative outcomes of being educated. The number of negative outcomes for a woman were summed. This was then reverse coded by being subtracted summation from the highest sum for all women (5).	NA
Perceived number of positive outcomes of being educated	125	2.69	±1.14	4.13	±1.22	continuous	Women were asked to free-list what they thought were the positive and negative outcomes of being educated. The number of positive outcomes for a woman were summed.	NA
Importance of children attending school	130	2.62	±0.66	2.23	±0.89	categorical	How important a woman thought it was for her sons or daughters to attend school.	0 = not important, 1 = a little important, 2 = important, 3 = very important
Importance of children being bilingual	130	2.52	±0.70	2.17	±0.90	categorical	How important a woman thought it was for her sons or daughters speak Spanish.	0 = not important, 1 = a little important, 2 = important, 3 = very important
Importance of children being literate	130	2.45	±0.74	2.22	±0.87	categorical	How important a woman thought it was for her sons or daughters to be able to read and write in Spanish.	0 = not important, 1 = a little important, 2 = important, 3 = very important
Educational aspirations for children (separated by sex of child talking about in analyses)								
School grade want for children	100	7.32	±1.19	6.94	±1.58	continuous	Women stated the grade they wanted their sons and daughters to have completed when they stop attending school.	NA
Want children to get a *bachiller*	99	0.67	±0.47	0.61	±0.49	binary	Whether women stated that they wanted their sons or daughters to complete high school	0 = no, 1 = yes
Reproductive preferences (separated by sex of child talking about in analyses)								
Preferred age at marriage	126	20.75	±4.64	18.77	±2.76	continuous	The age women would prefer their sons or daughters to be when they first marry.	NA
Preferred age at first birth	126	22.25	±5.03	20.27	±2.84	continuous	The age women would prefer their sons or daughters to be when they have their first child.	NA
Preferred time from marriage to first birth	126	1.50	±1.33	1.50	±0.94	continuous	Preferred age at marriage subtracted from preferred age at first birth.	NA

Table 4. Correlation matrix of the five questions that assessed women's perceived returns to investments in educational capital and the principles components and composite measures used to assess women's level of market integration.

		Age	Parity	PC Educational capital	PC Access to town	PC Ownership of luxury items	Access to wage labor for men	Access to wage labor for women	Positive outcomes of sons being educated	Negative outcomes of sons being educated	Importance of sons attending school	Importance of sons being bilingual	Importance of sons being literate	Positive outcomes of daughters being educated	Negative outcomes of daughters being educated	Importance of daughters attending school	Importance of daughters being bilingual	Importance of daughters being literate
Age	*r*	1	.763***	-.449***	-.091	.163	-.024	-.057	-.005	-.049	-.124	-.063	.012	-.021	-.074	-.032	-.162	-.155
	N	172	154	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130
Parity	*r*	.763***	1	-.412***	-.119	.213*	.021	-.096	-.112	-.043	-.051	-.099	-.056	-.025	-.143	-.007	-.159	-.175
	N	154	154	89	89	89	110	110	110	110	115	115	115	110	110	115	115	115
PC Educational capital	*r*	-.449***	-.412***	1	.000	.000	-.001	.177	.090	-.027	.036	.012	.207*	.160	.214*	.079	.280**	.262**
	N	99	89	99	99	99	96	96	96	96	99	99	99	96	96	99	99	99
PC Access to town	*r*	-.091	-.119	.000	1	.000	-.140	-.195	.298**	.271**	.199*	.202*	.241*	.223*	.278**	.085	.193	.304**
	N	99	89	99	99	99	96	96	96	96	99	99	99	96	96	99	99	99
PC Ownership of luxury items	*r*	.163	.213*	.000	.000	1	-.031	-.072	.132	.035	.194	.104	.121	.066	-.096	.055	-.020	.052
	N	99	89	99	99	99	96	96	96	96	99	99	99	96	96	99	99	99
Access to wage labor for men	*r*	-.024	.021	-.001	-.140	-.031	1	.101	-.024	.117	.108	-.098	-.217*	-.146	-.250**	-.228*	-.259**	-.179*
	N	125	110	96	96	96	125	125	125	125	125	125	125	125	125	125	125	125
Access to wage labor for women	*r*	-.057	-.096	.177	-.195	-.072	.101	1	.043	.009	.011	.100	.067	.025	.029	.047	.045	.065
	N	125	110	96	96	96	125	125	125	125	125	125	125	125	125	125	125	125
Positive outcomes of sons being educated	*r*	-.005	-.112	.090	.298**	.132	-.024	.043	1	.535***	.500***	.406***	.325***	.377***	.254**	.162	.373***	.400***
	N	125	110	96	96	96	125	125	125	125	125	125	125	125	125	125	125	125
Negative outcomes of sons educated	*r*	-.049	-.043	-.027	.271**	.035	.117	.009	.535***	1	.708***	.527***	.400***	.232**	.245**	.073	.289**	.279***
	N	125	110	96	96	96	125	125	125	125	125	125	125	125	125	125	125	125
Importance of sons attending school	*r*	-.124	-.051	.036	.199*	.194	.108	.011	.500***	.708***	1	.532***	.528***	.374***	.211*	.240***	.329***	.321***
	N	130	115	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130
Importance of sons being bilingual	*r*	-.063	-.099	.012	.202*	.104	-.098	.100	.406***	.527***	.532***	1	.576***	.415***	.434***	.390***	.564***	.508***
	N	130	115	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130
Importance of sons being literate	*r*	.012	-.056	.207*	.241*	.121	-.217*	.067	.325***	.400***	.528***	.576***	1	.415***	.392***	.287***	.526***	.575***
	N	130	115	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130
Positive outcomes of daughters educated	*r*	-.021	-.025	.160	.223*	.066	-.146	.025	.377***	.232**	.374***	.415***	.415***	1	.699***	.618***	.500***	.506***
	N	125	110	96	96	96	125	125	125	125	125	125	125	125	125	125	125	125
Negative outcomes daughters educated	*r*	-.074	-.143	.214*	.278**	-.096	-.250**	.029	.254**	.245**	.211*	.434***	.392***	.699***	1	.674***	.668***	.570***
	N	125	110	96	96	96	125	125	125	125	125	125	125	125	125	125	125	125
Importance of daughters attending school	*r*	-.032	-.007	.079	.085	.055	-.228*	.047	.162	.073	.240**	.390***	.287***	.618***	.674***	1	.453***	.380***
	N	130	115	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130
Importance of daughters bilingual	*r*	-.162	-.159	.280**	.193	-.020	-.259**	.045	.373***	.289***	.329***	.564***	.526***	.500***	.668***	.453***	1	.691***
	N	130	115	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130
Importance of daughters literate	*r*	-.155	-.175	.262**	.304**	.052	-.179*	.065	.400***	.279**	.321***	.508***	.575***	.506***	.570***	.380***	.691***	1
	N	130	115	99	99	99	125	125	125	125	130	130	130	125	125	130	130	130

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Table 5. Correlation matrix for the two measures of educational aspirations for children, the four measures of reproductive preferences for sons and daughters, and the principles components and composite measures used to assess women's level of market integration and prECI for sons and daughters.

		Age	Parity	Education capital	Access to town	Own luxury items	Access wage labor men	Access wage labor women	prECI daughters	prECI sons	School grade want daughters	Want bachiller daughters	School grade want son	Want bachiller sons	Pref. age at marriage daughters	Pref. age at first birth daughters	Pref. time marriage to first birth daughters	Pref. age at marriage sons	Pref. age at first birth sons	Pref. time marriage to first birth sons
Age	*r*	1	.763***	-.449***	-.091	.163	-.024	-.057	-.098	-.058	-.090	-.044	-.026	.001	-.025	.008	.099	-.025	.021	.167
	N	172	154	99	99	99	125	125	125	125	100	100	99	99	126	126	126	126	126	126
Parity	*r*	.763***	1	-.412***	-.119	.213*	.021	-.096	-.119	-.072	-.165	-.111	-.125	-.082	-.114	-.082	.087	.129	.148	.105
	N	154	154	89	89	89	110	110	110	110	89	89	88	88	113	113	113	113	113	113
Educational capital	*r*	-.449***	-.412***	1	.000	.000	-.001	.177	.247*	.107	.248*	.192	.159	.056	.116	.118	.015	.099	.074	-.093
	N	99	89	99	99	99	96	96	96	96	79	79	78	78	98	98	98	98	98	98
Access to town	*r*	-.091	-.119	.000	1	.000	-.140	-.195	.269**	.289**	.311**	.345**	.384***	.526***	.082	.092	.038	.155	.131	-.059
	N	99	89	99	99	99	96	96	96	96	79	79	78	78	98	98	98	98	98	98
Ownership luxury items	*r*	.163	.213*	.000	.000	1	-.031	-.072	.020	.129	-.115	.080	.042	.085	.075	.058	-.044	.249*	.240*	.055
	N	99	89	99	99	99	96	96	96	96	79	79	78	78	98	98	98	98	98	98
Access wage labor men	*r*	-.024	.021	-.001	-.140	-.031	1	.101	-.262**	-.019	-.254*	-.264**	.041	-.115	-.061	-.053	.019	-.081	-.099	-.092
	N	125	110	96	96	96	125	125	125	125	100	100	99	99	123	123	123	123	123	123
Access to wage labor for women	*r*	-.057	-.096	.177	-.195	-.072	.101	1	.051	.057	.121	.043	.060	-.043	.128	.141	.050	.091	.073	-.044
	N	125	110	96	96	96	125	125	125	125	100	100	99	99	123	123	123	123	123	123
prECI for daughters	*r*	-.098	-.119	.247*	.269**	.020	-.262**	.051	1	.551***	.557***	.508***	.365***	.443***	.188*	.167	-.047	.276**	.241**	-.049
	N	125	110	96	96	96	125	125	125	125	100	100	99	99	123	123	123	123	123	123
prECI for sons	*r*	-.058	-.072	.107	.289**	.129	-.019	.057	.551***	1	.310**	.338***	.431***	.476***	.141	.136	-.003	.262**	.236**	-.021
	N	125	110	96	96	96	125	125	125	125	100	100	99	99	123	123	123	123	123	123
School grade want daughters	*r*	-.090	-.165	.248*	.311**	-.115	-.254*	.121	.557***	.310**	1	.842***	.636***	.686***	.185	.134	-.131	.311**	.270**	-.082
	N	100	89	79	79	79	100	100	100	100	100	100	92	92	100	100	100	100	100	100
Want bachiller for daughters	*r*	-.044	-.111	.192	.345**	.080	-.264**	.043	.508***	.338***	.842***	1	.558***	.701***	.289**	.218*	-.183	.328***	.297**	-.037
	N	100	89	79	79	79	100	100	100	100	100	100	92	92	100	100	100	100	100	100
School grade want sons	*r*	-.026	-.125	.159	.384***	.042	.041	.060	.365***	.431***	.636***	.558***	1	.848***	.168	.165	.001	.263**	.227*	-.081
	N	99	88	78	78	78	99	99	99	99	92	92	99	99	99	99	99	99	99	99
Want bachiller sons	*r*	.001	-.082	.056	.526***	.085	-.115	-.043	.443***	.476***	.686***	.701***	.848***	1	.196	.164	-.078	.291**	.268**	-.021
	N	99	88	78	78	78	99	99	99	99	92	92	99	99	99	99	99	99	99	99
Preferred age at marriage daughters	*r*	-.025	-.114	.116	.082	.075	-.061	.128	.188*	.141	.185	.289**	.168	.196	1	.944***	-.084	.351***	.365***	.158
	N	126	113	98	98	98	123	123	123	123	100	100	99	99	126	126	126	126	126	126
Preferred age at first birth daughters	*r*	.008	-.082	.118	.092	.058	-.053	.141	.167	.136	.134	.218*	.165	.164	.944***	1	.250**	.350***	.389***	.254**
	N	126	113	98	98	98	123	123	123	123	100	100	99	99	126	126	126	126	126	126
Preferred time marriage to first birth daughters	*r*	.099	.087	.015	.038	-.044	.019	.050	-.047	-.003	-.131	-.183	.001	-.078	-.084	.250**	1	.026	.104	.302***
	N	126	113	98	98	98	123	123	123	123	100	100	99	99	126	126	126	126	126	126
Preferred age at marriage sons	*r*	-.025	.129	.099	.155	.249*	-.081	.091	.276**	.262**	.311**	.328***	.263**	.291**	.351***	.350***	.026	1	.965***	.165
	N	126	113	98	98	98	123	123	123	123	100	100	99	99	126	126	126	126	126	126
Preferred age at first birth sons	*r*	.021	.148	.074	.131	.240*	-.099	.073	.241**	.236**	.270**	.297**	.227*	.268**	.365***	.389***	.104	.965***	1	.417***
	N	126	113	98	98	98	123	123	123	123	100	100	99	99	126	126	126	126	126	126
Preferred from marriage to first birth sons	*r*	.167	.105	-.093	-.059	.055	-.092	-.044	-.049	-.021	-.082	-.037	-.081	-.021	.158	.254**	.302***	.165	.417***	1
	N	126	113	98	98	98	123	123	123	123	100	100	99	99	126	126	126	126	126	126

† = $p < 0.10$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Table 6. Women's educational capital and access to town are positively associated with prECI for daughters, and partially mediates their relationship with highest school grade desired for daughters. Estimated coefficients (b), standard error of these coefficients (SE), critical ration, standardized estimated coefficient (β) and p-value (p) are shown. Error terms for each model are also shown (e1 and e2). For visualizations of these models see Appendix Figure 5. Standardized coefficients significant at p < 0.05 are in bold.

	Model 1a (no prECI)					Model 1b (full model with prECI)					Model 1c (constrained model with prECI)				
Relationship	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**
Regression path to prECI for daughters															
Educational capital	-	-	-	-	-	0.221	0.102	2.168	**0.213**	0.03	0.214	0.102	2.100	**0.206**	0.036
Access to town	-	-	-	-	-	0.295	0.106	2.779	**0.273**	0.005	0.301	0.106	2.833	**0.279**	0.005
Ownership of luxury items	-	-	-	-	-	-0.008	0.124	-0.063	-0.006	0.950	-	-	-	-	-
Access to wage labor for women	-	-	-	-	-	-0.043	0.115	-0.372	-0.037	0.710	-	-	-	-	-
Error term	-	-	-	-	-	0.902	0.134	6.745	-	< 0.001	0.903	0.134	6.745	-	< 0.001
Regression path to preferred age of marriage for daughters															
Educational capital	1.166	0.28	4.164	**0.384**	< 0.001	1.025	0.279	3.669	**0.337**	< 0.001	1.060	0.281	3.766	**0.348**	< 0.001
Access to town	0.817	0.291	2.807	**0.259**	0.005	0.629	0.295	2.133	**0.199**	0.033	0.618	0.298	2.075	**0.195**	0.038
Ownership of luxury items	0.324	0.340	0.952	0.088	0.341	0.329	0.331	0.994	0.089	0.320	-	-	-	-	-
Access to wage labor for women	0.231	0.315	0.732	0.067	0.464	0.258	0.307	0.841	0.075	0.400	-	-	-	-	-
prECI for daughters	-	-	-	-	-	0.639	0.280	2.281	**0.218**	0.023	0.628	0.282	2.225	**0.214**	0.026
Error term	6.805	1.009	6.745	-	< 0.001	6.437	0.954	6.745	-	< 0.001	6.553	0.971	6.745	-	< 0.001

† = $p < 0.10$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Table 7. Women's *educational capital* positively predicts highest school grade desired for sons. Women's access to town is positively associated with *prECI for sons*, and *prECI for sons* partially mediates its relationship with highest school grade desired for sons. Estimated coefficients (b), standard error of these coefficients (SE), critical ration, p-value (p), and standardized estimated coefficient (β) are shown. Error terms for each model are also shown (e1 and e2). For visualizations of these models see Appendix Figure 6. Standardized coefficients significant at p < 0.05 are in bold.

	Model 2a (no prECI)					**Model 2b (full model with prECI)**					**Model 2c (constrained model with prECI)**				
Relationship	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**	**b**	**±SE**	**Critical ratio**	**β**	**p**
Regression path to prECI for sons															
Educational capital	-	-	-	-	-	0.077	0.097	0.791	0.079	0.429	-	-	-	-	-
Access to town	-	-	-	-	-	0.293	0.101	2.898	**0.289**	0.004	0.298	0.102	2.929	**0.294**	0.003
Ownership of luxury items	-	-	-	-	-	0.081	0.118	0.684	0.068	0.494	-	-	-	-	-
Access to wage labor for men	-	-	-	-	-	-0.130	0.258	-0.504	-0.050	0.614	-	-	-	-	-
Error term						0.819	0.121	6.745	-	< 0.001	0.829	0.123	6.745	-	< 0.001
Regression path to preferred age of marriage for sons															
Educational capital	1.148	0.285	4.032	**0.371**	< 0.001	1.074	0.270	3.980	**0.347**	< 0.001	1.085	0.269	4.032	**0.353**	< 0.001
Access to town	0.983	0.296	3.32	**0.305**	< 0.001	0.701	0.292	2.399	**0.218**	0.016	0.693	0.293	2.365	**0.217**	0.018
Ownership of luxury items	-0.075	0.346	-0.215	-0.020	0.829	-0.152	0.328	-0.465	-0.040	0.642	-	-	-	-	-
Access to wage labor for men	0.007	0.756	0.010	0.001	0.992	0.132	0.715	0.185	0.016	0.853	-	-	-	-	-
prECI for sons	-	-	-	-	-	0.962	0.290	3.314	**0.303**	< 0.001	0.951	0.289	3.291	**0.302**	0.001
Error term	7.034	1.043	6.745	-	< 0.001	6.277	0.930	6.745	-	< 0.001	6.293	0.933	6.745	-	< 0.001

† = $p < 0.10$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Table 8. *prECI* partially mediates the relationship between women's *educational capital* and *access to town*, and their highest school grade desired for daughters. *prECI for sons* partially mediated the relationship between women's *access to town* and their highest school grade desired for sons. For sons, the relationship between women's *educational capital* and highest school grade desired is not mediated by *prECI for sons.* Bootstrapping (20,0000) was used in IBM SPSS AMOS (v.24) to assess whether prECI is a mediator. Standardized direct and indirect effects shown.

Model	Hypothesis	Direct	Indirect	Result
Daughters				
1b	Educational capital → prECI → highest school grade desired	0.337***	0.046**	Partial mediation
	Access to town → prECI → highest school grade desired	0.199†	0.060**	Partial mediation
	Ownership of luxury items → prECI → highest school grade desired	0.089	-0.001	No relationship
	Access to wage labor → prECI → highest school grade desired	0.075	-0.008	No mediation
	prECI → highest school grade desired	0.218*	NA	Direct relationship
1c	Educational capital → prECI → highest school grade desired	0.348***	0.044*	Partial mediation
	Access to town → prECI → highest school grade desired	0.195†	0.06*	Partial mediation
	prECI → highest school grade desired	0.214*		Direct relationship
Sons				
2b	Educational capital → prECI → highest school grade desired	0.347***	0.024	No relationship
	Access to town → prECI → highest school grade desired	0.218*	0.087**	Full mediation
	Ownership of luxury items → prECI → highest school grade desired	-0.04	0.021	No mediation
	Access to wage labor → prECI → highest school grade desired	0.016	-0.015	No relationship
	prECI → highest school grade desired	0.303**		Direct relationship (?)
2c	Educational capital → prECI → highest school grade desired	0.353***		Direct relationship
	Access to town → prECI → highest school grade desired	0.217*	.283**	Partial mediation
	prECI → highest school grade desired	0.302**		Direct relationship

† = $p < 0.10$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$

Table 9. Goodness-of-fit statistics and model comparisons for the full and constrained models for women's highest school grade desired for their children.

	Goodness-of-fit index criteria[b]										Model comparisons						R²	
Model[a]	χ^2	*df*	*p*	RMR	GFI	AGFI	IFI	CFI	TLI	RMSEA	χ^2 diff.	*df*	*p*	AIC	BCC	CAIC	prECI	Preferred age of marriage
Daughters																		
1a	6.924	6	0.328	0.062	0.97	0.926	0.962	0.955	0.924	0.0410				24.924	26.195	56.620		0.227
1b	6.924	6	0.328	0.053	0.975	0.914	0.977	0.971	0.928	0.0410				36.924	39.424	89.751	0.121	0.268
1c	0.044	1	0.835	0.017	1.000	0.998	1.026	1.000	1.177	<0.001	6.88	5	0.230	18.044	19.090	49.740	0.120	0.259
Sons																		
2a	2.936	6	0.817	0.032	0.988	0.969	1.151	1.000	1.313	<0.001				20.936	22.207	52.632		0.231
2b	2.936	6	0.817	0.028	0.990	0.964	1.077	1.000	1.247	<0.001				32.936	35.436	85.763	0.097	0.314
2c	0.533	2	0.766	0.043	0.997	0.985	1.036	1.000	1.121	<0.001	2.403	4	0.662	16.533	17.464	44.708	0.086	0.301

Table 10. Child sex does not moderate the relationship between *educational capital* and highest school grade desired for children. However, it does moderate the relationships between prECI and highest school grade desired for children. Standardized coefficients from general linear mixed models, with women's ID as a random effect, are shown. Corrected Akaike information criterion (AIC_C), shown here, suggest that Model 3f best fits the data than the no-interaction term model (Model 3a).

	Model 3a			Model 3b			Model 3c			Model 3d			Model 3e			Model 3f		
Variable	β	±SD	p	β	±SD	p	β	±SD	p	β	±SD	p	β	±SD	p	β	±SD	p
Intercept	0.028	0.094	0.768	0.027	0.095	0.777	0.030	0.095	0.753	0.026	0.094	0.786	0.048	0.113	0.670	0.036	0.092	0.696
Educational capital	0.347	0.082	<0.001	0.358	0.091	<0.001	0.347	0.082	<0.001	0.346	0.082	<0.001	0.347	0.082	<0.001	0.360	0.080	<0.001
Access to town	0.231	0.084	0.006	0.231	0.084	0.006	0.251	0.093	0.008	0.230	0.084	0.007	0.232	0.084	0.006	0.248	0.082	0.003
Ownership of luxury items	0.027	0.082	0.742	0.027	0.082	0.743	0.027	0.082	0.741	-0.033	0.091	0.719	0.028	0.082	0.734	0.055	0.080	0.489
Access to wage labor	0.073	0.059	0.221	0.075	0.060	0.214	0.068	0.060	0.256	0.077	0.059	0.194	0.028	0.148	0.850	0.080	0.059	0.173
prECI	0.183	0.065	0.005	0.186	0.066	0.005	0.184	0.065	0.006	0.189	0.065	0.004	0.184	0.065	0.005	0.172	0.065	0.008
Child sex (0 = male, 1 = female)	-0.056	0.097	0.567	-0.054	0.098	0.585	-0.060	0.098	0.543	-0.051	0.097	0.597	-0.073	0.111	0.511	-0.057	0.097	0.557
Interaction terms																		
Educational capital * child sex	-	-	-	-0.023	0.082	0.774	-	-	-	-	-	-	-	-	-	-	-	-
Access to town * child sex	-	-	-	-	-	-	-0.040	0.081	0.624	-	-	-	-	-	-	-	-	-
Ownership of luxury items * child sex	-	-	-	-	-	-	-	-	-	0.119	0.080	0.139	-	-	-	-	-	-
Access to wage labor * child sex	-	-	-	-	-	-	-	-	-	-	-	-	0.052	0.157	0.328	-	-	-
prECI * child sex																-0.193	0.076	0.012
AIC_C	447.07			450.164			450.013			448.081			448.832			444.114		

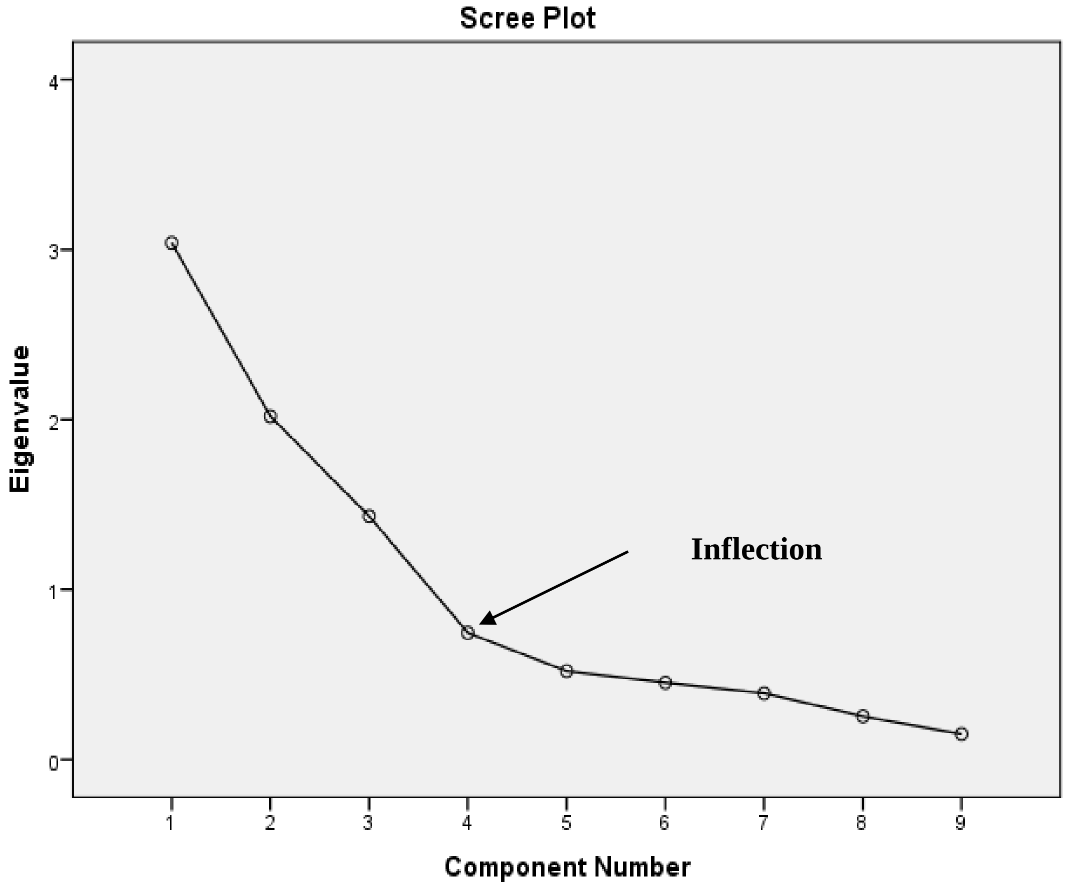


Figure 1. Scree plot from PCA of eight questions assessing women's level of market integration. Three components have eigenvalues greater than one.

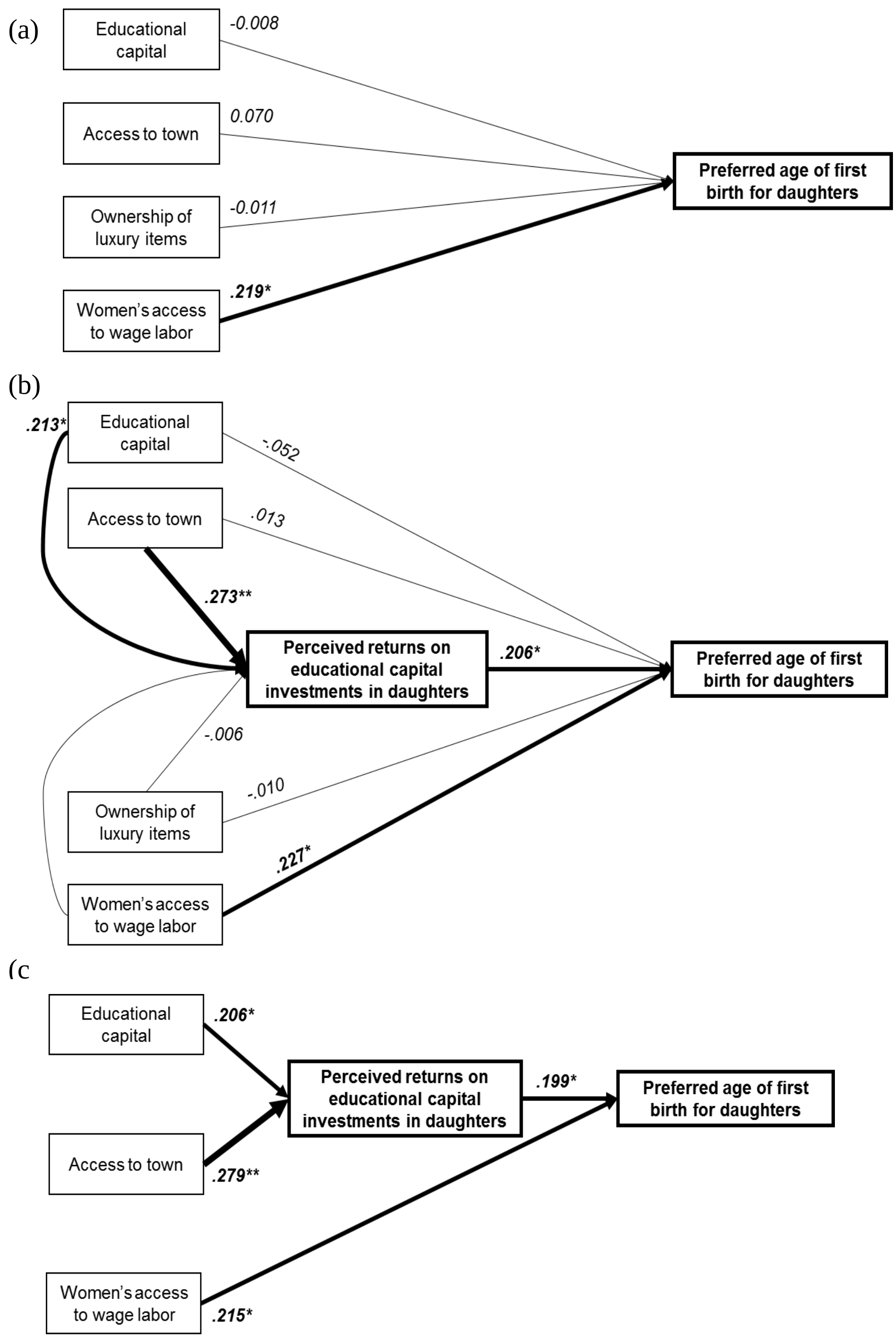


Figure 2. Path analysis of the pathways between women's educational capital and their preferred age of first birth for daughters. (a) No prECI (Table 6 Model 1a). (b) The full model with prECI (Table 6 Model 1b). (c) A constrained model with all regression pathways with p > 0.05 removed (Table 6 Model 1c). Standardized coefficients are shown. Coefficients in bold are significant at * = p < 0.05 and ** = p < 0.01.

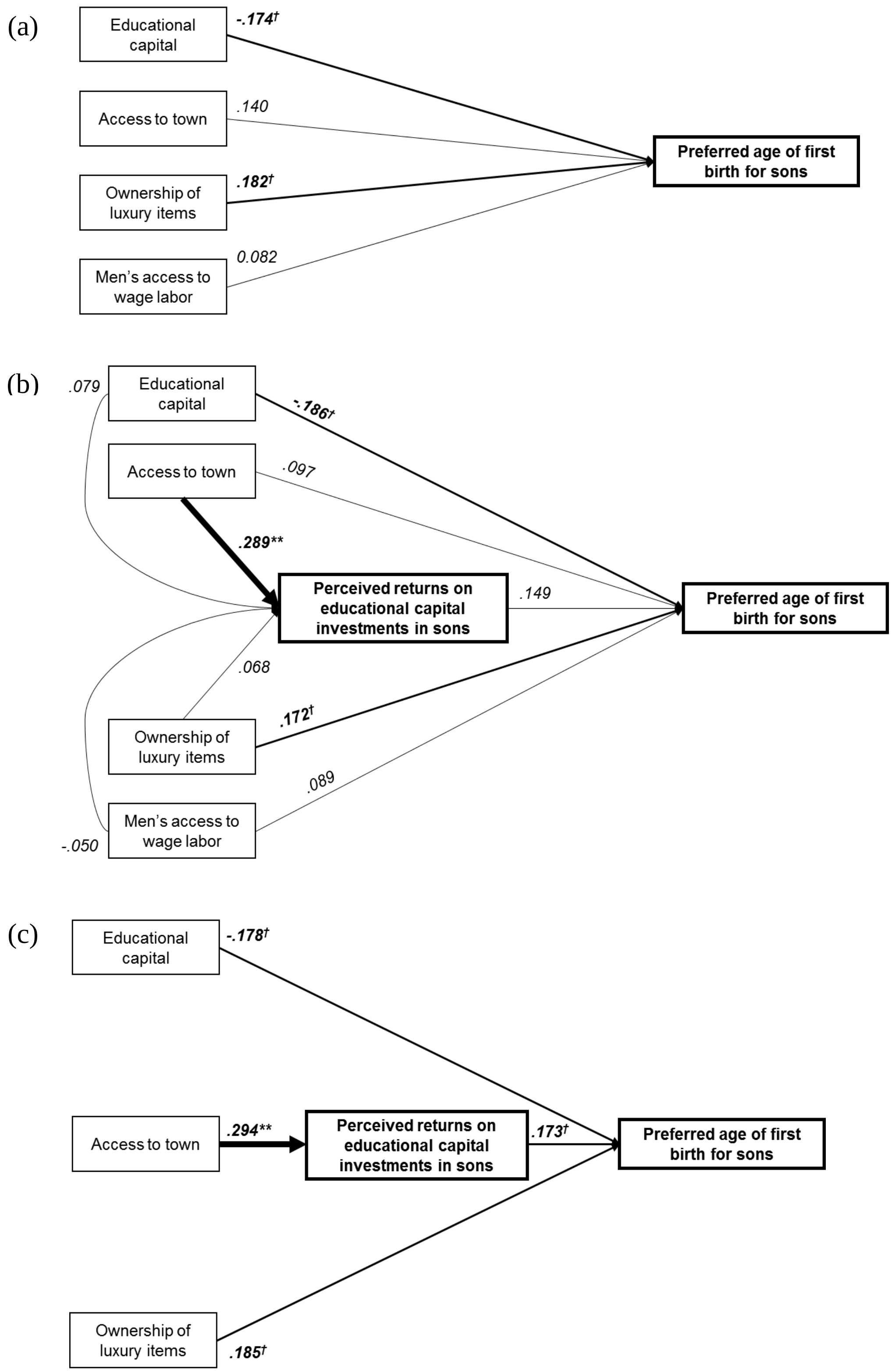


Figure 3. Path analysis of the pathways between women's educational capital and their preferred age of first birth for sons. (a) No prECI (Table 9 Model 2a). (b) The full model with prECI (Table 9 Model 2b). (c) A constrained model with all regression pathways with $p > 0.05$ removed (Table 9 Model 2c). Standardized coefficients are shown. Coefficients in bold are significant at † = $p < 0.05$ and ** = $p < 0.01$.

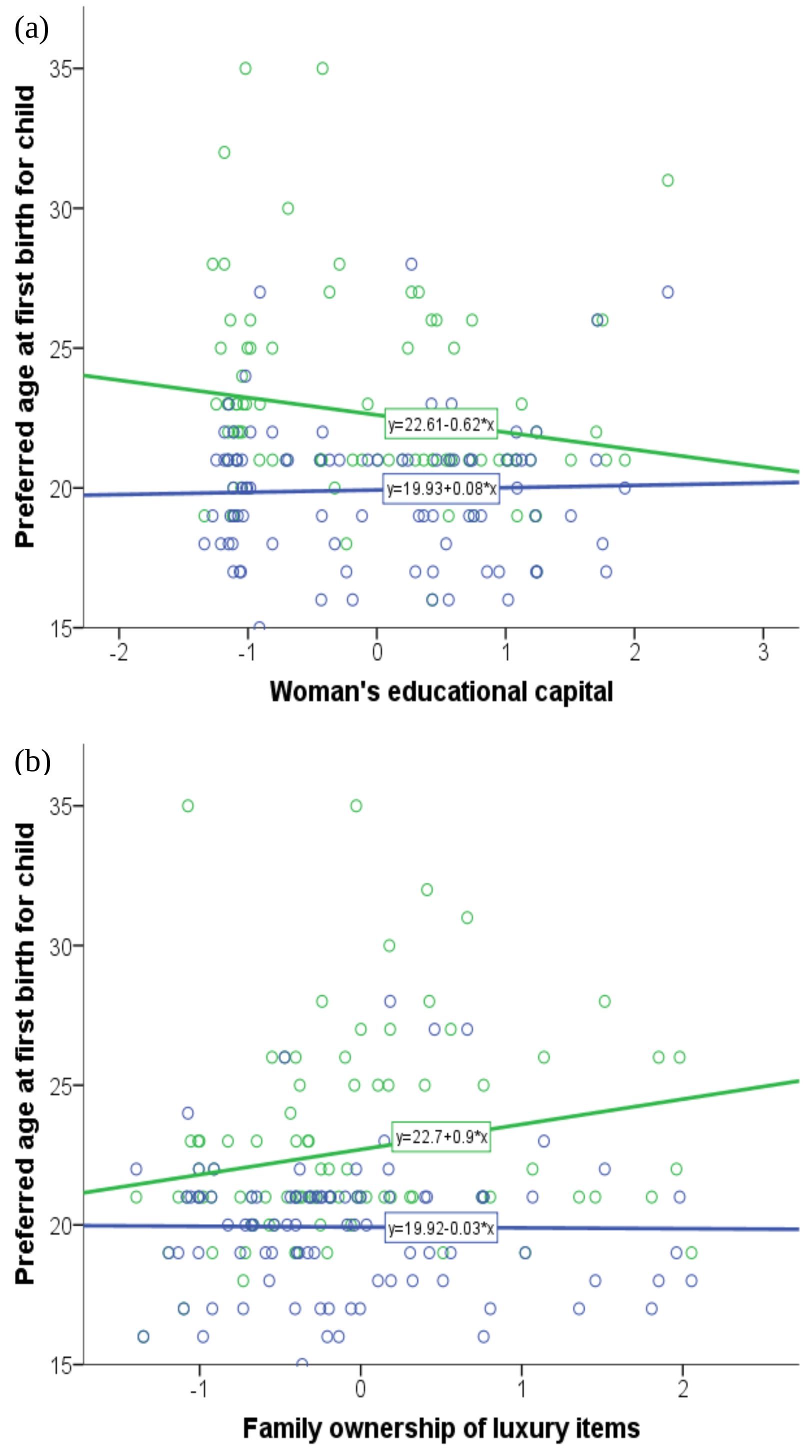


Figure 4. Scatter graphs showing that the sex of the child a woman is talking about affects the relationships of (a) educational capital, (b) access to town and (c) ownership of luxury items with preferred age at first birth for children.

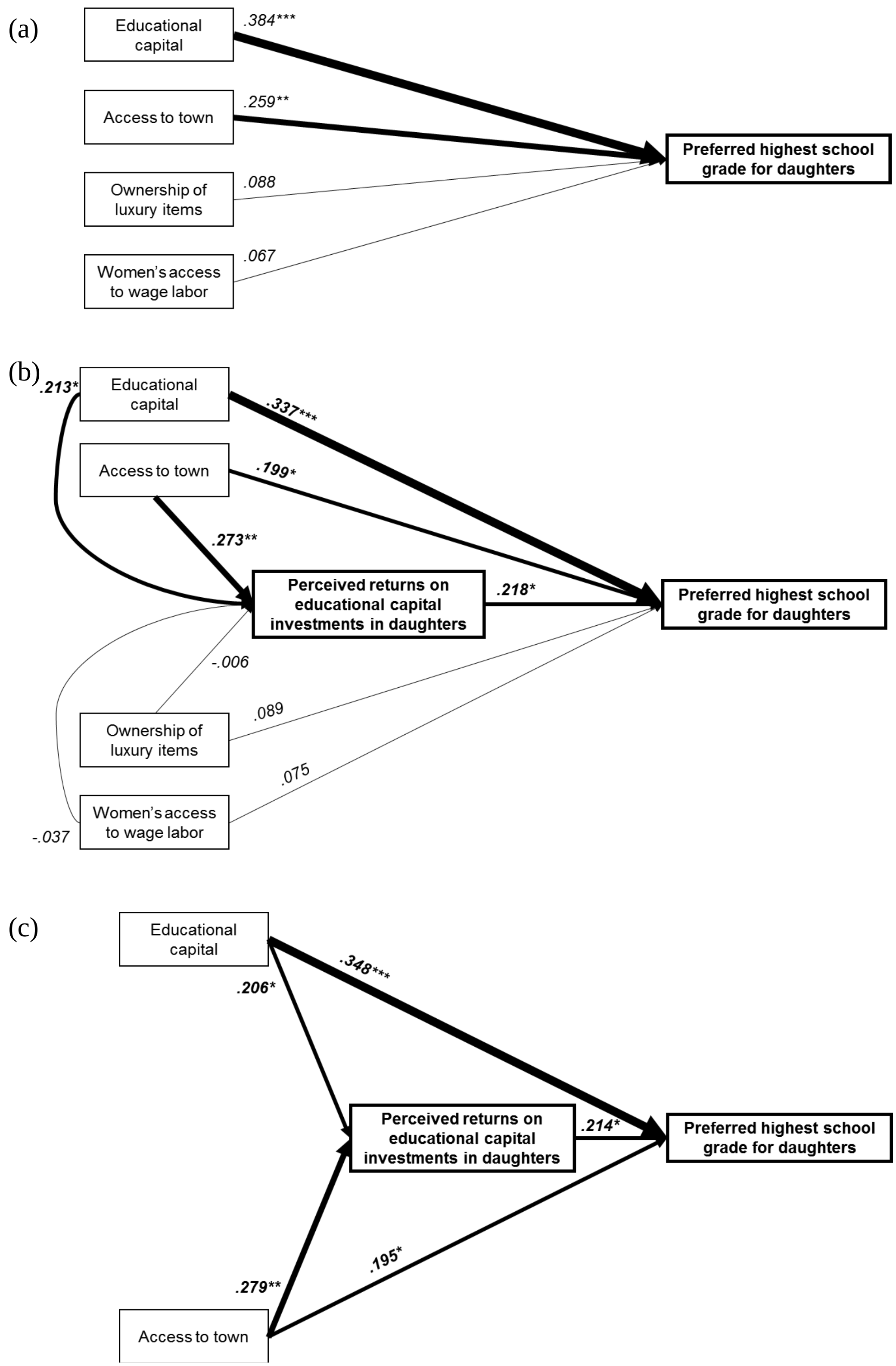


Figure 5. Pathways between women's *educational capital* and highest school grade desired for daughters. (a) No prECI; (b) The full model with prECI; (c) A constrained model with all regression pathways with $p >$ 0.05 removed. Standardized coefficients shown. * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

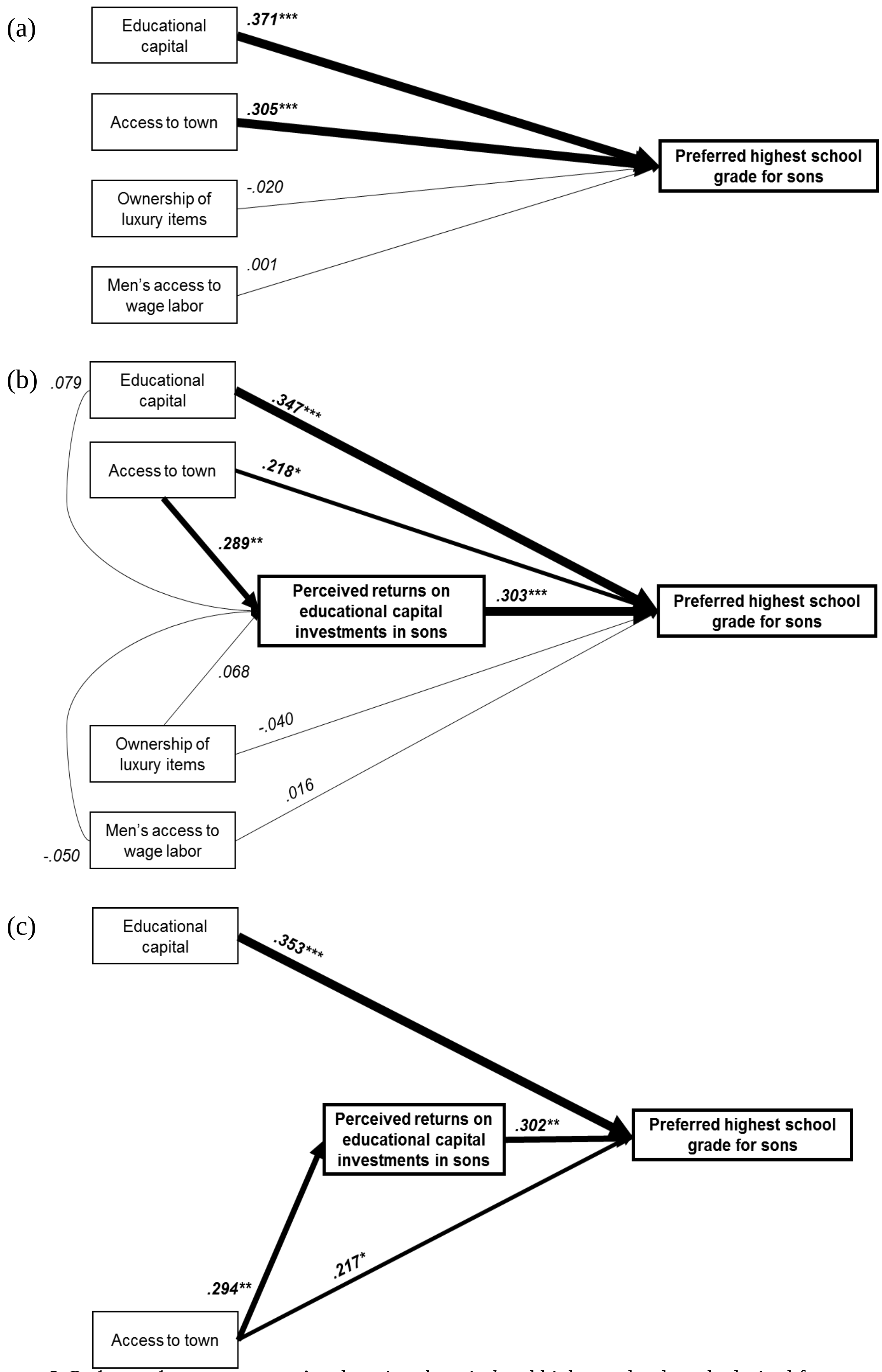


Figure 6. Pathways between women's *educational capital* and highest school grade desired for sons. (a) No prECI; (b) The full model with prECI; (c) A constrained model with all regression pathways with $p > 0.05$ removed. Standardized coefficients shown. * = $p < 0.05$; ** = $p < 0.01$; *** = p < 0.001.